REPORT RESUMES

ED 020 620 EF 000 236

RESEARCH IN CLASSROOM THERMAL ENVIRONMENT AT GARDENHILL SCHOOL IN LA MIRADA, CALIFORNIA.

BY- HOWATT, CLARKE T.

UNIVERSITY OF SOUTHERN CALIFORNIA, LOS ANGELES

PUB DATE 61

EDRS PRICE MF-$0.50 HC-$2.48 60P.

DESCRIPTORS- *AIR CONDITIONING EQUIPMENT, *HEATING, *THERMAL ENVIRONMENT, CLASSROOM ENVIRONMENT, CLIMATE CONTROL, TEMPERATURE, CALIFORNIA

THIS IS A FINAL REPORT OF A STUDY OVER A FOURTEEN MONTH PERIOD FROM APRIL, 1959 TO JUNE, 1960 OF HEATING AND COOLING TWO SCHOOL CLASSROOMS AND A COMPARISON WITH A THIRD CLASSROOM IN WHICH THERE WAS HEATING AND FRESH AIR CIRCULATION ONLY. ALL THREE ROOMS HAD AN AIR-FLOW DISTRIBUTION SYSTEM. A TYPHOON HEAT PUMP PROVIDED HEATING AND COOLING IN ONE ROOM AND AN ARKLA-SERVEL ABSORPTION UNIT SERVED THE OTHER. THE THIRD ROOM WAS HEATED BY A HAYES DIRECT FIRED GAS FURNACE. OBJECTIVES OF THE STUDY WERE--(1) TO DETERMINE THERMAL DIFFERENCES BETWEEN THE TWO ROOMS WHICH WERE HEATED AND COOLED AND THE THIRD WHICH HAD ONLY HEATING AND VENTILATION, (2) TO DETERMINE HOURS OF COOLING AND HEATING, (3) TO DETERMINE COOLING LOADS AS THEY VARY WITH OUTSIDE TEMPERATURE AND THE EFFECT OF AIRFLOOR, AND (4) TO DETERMINE UTILITIES CONSUMPTION OF THE HEAT PUMP, ABSORPTION UNIT, AND THE CONVENTIONAL FURNACE. NUMEROUS VARIABLES WERE CONTROLLED FOR MORE ACCURATE COMPARISON. A SUPPLEMENT CONTAINS AN OPERATING COST ANALYSIS. (RH)

J. G. STRONG CO.
5054 La Crosse Lane
Madison 5, Wis.
CEdar 8-5013

RESEARCH IN CLASSROOM THERMAL ENVIRONMENT

AT GARDENHILL SCHOOL IN LA MIRADA, CALIFORNIA

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
OFFICE OF EDUCATION

THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL OFFICE OF EDUCATION POSITION OR POLICY.

Prepared for
Airfloor Company of California, Inc.
Southern California Edison Company
Southern California Gas Company

By Clarke T. Howatt

Assistant Professor
Department of Mechanical Engineering
University of Southern California

1961

CLARKE T. HOWATT
ENGINEERING CONSULTANT
6478 NANCY STREET
LOS ANGELES 45

Los Angeles, California
April, 1961

Airfloor Company of California, Inc.
Southern California Edison Company
Southern California Gas Company
c/o Southern California Gas Company
Downey, California

Subject: Final report, Classroom Thermal Environment Experiment

Gentlemen:

Attached is the final report for the Classroom Thermal Environment Experiment conducted at the Gardenhill School, La Mirada, California, from April 9, 1959 through June 17, 1960. This report is a compilation of selected material presented in the monthly reports, in addition to a description of the test, test data, and a discussion of the results obtained during the 13 month test period. The temperature data is accurate to ± 1°F. except in cases where the data is used in the load analysis where the accuracy is increased by repeated instrument calibration to ± 0.5°F. The utility consumptions have the accuracy of commercial metering equipment as installed by the utilities.

Sincerely yours,

Clarke T. Howatt
Assistant Professor
University of Southern California

CTH:lg
5/22/61

Contents

Foreword 7
Summary 9
Layout of Test Facilities 11
Equipment 20
Utility Consumption and Hours of Operation 21
Thermal Environment 31
Load Analysis 55

Foreword

This is a study of heating and cooling two school classrooms and comparison between these two rooms and a third classroom in which there was heating and fresh air circulation only. All three of the rooms had an Airfloor air distribution system. The heating and cooling was accomplished in one room by a Typhoon Heat Pump, and in a second room by an Arkla-Servel Absorption Unit. The third room was heated by a Hayes Direct Fired Gas Furnace.

The objectives of this study were to determine the following:

1. Thermal differences between two classrooms equipped with heating and cooling and a third room equipped with heating and ventilation only, all three rooms using an Airfloor distribution system.
2. Hours of cooling and hours of heating.
3. Cooling loads as they vary with outside temperature and the effect of Airfloor on them.
4. Utilities consumption of the heat pump, absorption unit, and the conventional furnace.

The rooms with cooling were occupied by first grade children; the third room with heating only contained second grade children. The physical layout of the three rooms was the same. The two rooms with cooling had the same exposures and insulation, were subjected to approximately the same air circulation, had the same load as a result of natural elements, and approximately the same internal load. Both of these rooms had two walls that are common to adjoining rooms provided with cooling also. The third room was like the two rooms with cooling with the exception that it had no roof insulation, and two of its walls were common to adjoining rooms that had no cooling.

It was not the purpose of this study to evaluate psychological conditions or benefits to and reactions of students and teachers.

With the backing of the Norwalk-La Mirada School District and the support of the Architectural and Engineering firm of Kistner, Wright and Wright, consultants for the Norwalk-La Mirada School District, the Gardenhill Elementary School of La Mirada was selected as the site for the experiment.

A Typhoon Heat Pump, Model TAS 31 of three-ton capacity and an Arkla Servel, Model 500 air conditioner of three and one-half ton capacity were provided for the test. The equipment was installed in late fall of 1958, with the test beginning in April, 1959 and continuing into June, 1960.

The air distribution was through an Airfloor panel system. In this system the air was discharged from the heating-cooling units into a supply trench which runs below grade along one side of the classroom. From the trench the air, contained between a sub-slab and Airfloor forms, passed through the floor to the opposite side of the room where it was discharged into the room. After circulating across the room the air entered the return registers where it was mixed with fresh air and recirculated.

The design conditions were taken as follows:

WINTER

Outside — 35°F. db   Room — 70°F. db

SUMMER

Outside — 95°F. db   Room — 75°F. db

70°F. wb   50% RH

Kistner, Wright and Wright established the design sensible heat load on cooling to be 39,779 Btu per hour and on heating to be 25,418 Btu per hour. Their latent load calculation based on 31 people was 7,750 Btu per hour, giving a total load on cooling of 47,529 Btu per hour.

Summary

The experiment took place over a period of nearly fourteen months from the first of April, 1959 through the middle of June, 1960. During this time the daily outside high temperature ranged from 58°F. to 103°F., whereas the daily low ranged from 38°F. to 75°F. Several of the 100°F. plus days occurred on weekends, with no classes in session, and those which did not occur on weekends came during the latter part of June and July during which time the rooms were not occupied. However, there were several school days in which the high temperature exceeded 95°F. The graphs on pages 50 to 54 depict the room temperatures as they varied throughout the day for a 96°F. day. From the statistical analysis of the fourteen months, the data showed that the relationship between outside temperature and excess temperatures of non-cooled room over rooms provided with cooling existed as follows:

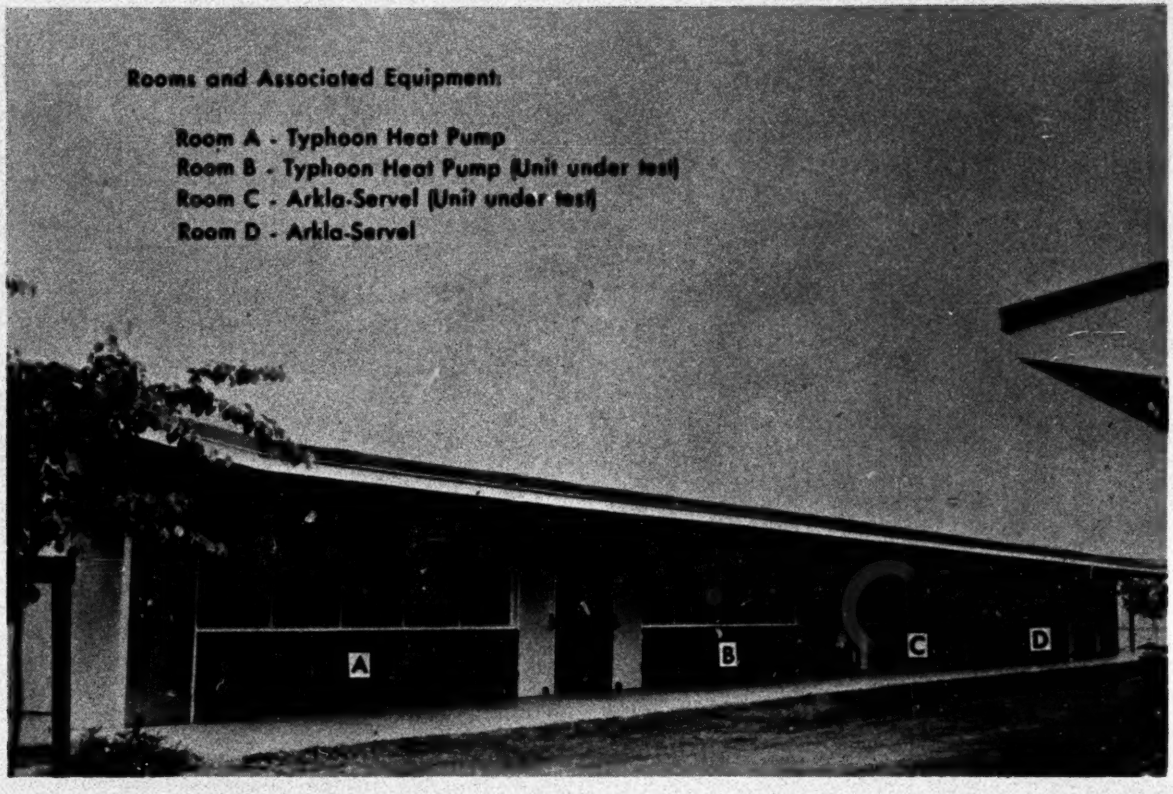
Outside High Temperature	Excess Temperature Of Non - Cooled Room Over Cooled Rooms
72°F.	2°F.
76°F.	3°F.
79°F.	4°F.
86°F.	5° — 6°F.
92°F.	6° — 8°F.
96°F.	9° —12°F.
100°F.	13°F.

With the thermostat settings in the cooled rooms set with 68°F. — 73°F. limits, the daily high temperature in the Typhoon room averaged between 75°F. and 77°F. When the outside temperature went in the high 90°F. range, both rooms had temperatures 2°F.—3°F. higher than these averages. A more comprehensive view of the thermal variation is given in the Thermal Environment Section.

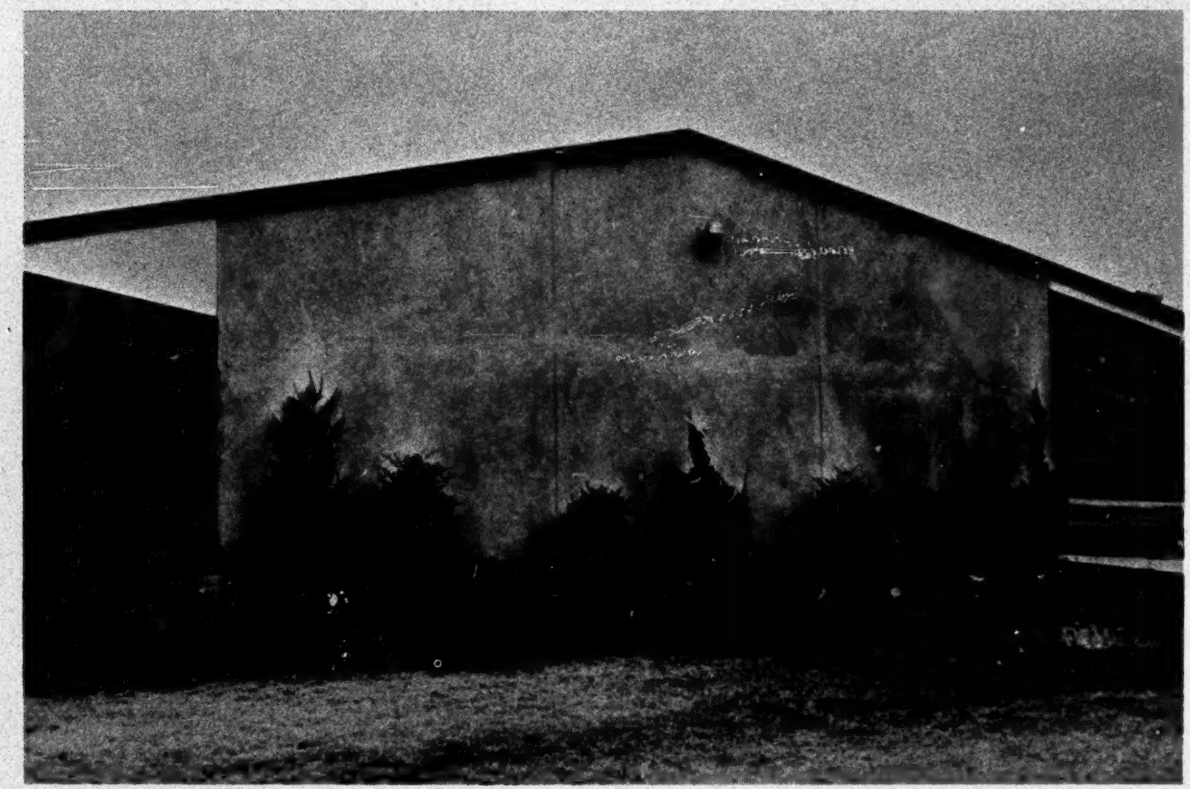
It was necessary for the units to provide cooling every day of the fourteen month period in which students occupied the classroom. The duration of cooling time was dependent both upon daytime temperature and the preceding nighttime temperature due to the "inertia" effect of the Airfloor concrete slab. The hours cooling versus temperature relationship is tabulated and shown graphically on pages 26 to 30, and is accompanied by an analysis in the discussion on pages 55 to 60.

A major portion of the data can be analysed only in light of the energy storage capacity of the Airfloor system. The thermal lag or "inertia" of the slab eliminates to a large extent the dependency between the number of cooling hours, the magnitude of cooling loads, and daily temperatures. The slab provided favorable conditions when the night temperatures were low, but not so low that room heating was required. Even with a sudden drop in outside temperature, the slab was able to supply sufficient energy to keep the room at design conditions, without unit heating, provided the temperature did not remain at the low value for an extended period. The slab, being cooled by the evening and early morning low temperature air, was then used as a heat sink later in the day. In *contrast* to this, when heating was required in the morning then, of course, when the units came on cooling, it was necessary to remove the energy previously stored in the slab due to the earlier heating. A more comprehensive study of the slab is given in the Load Analysis Section, pages 55 through 60.

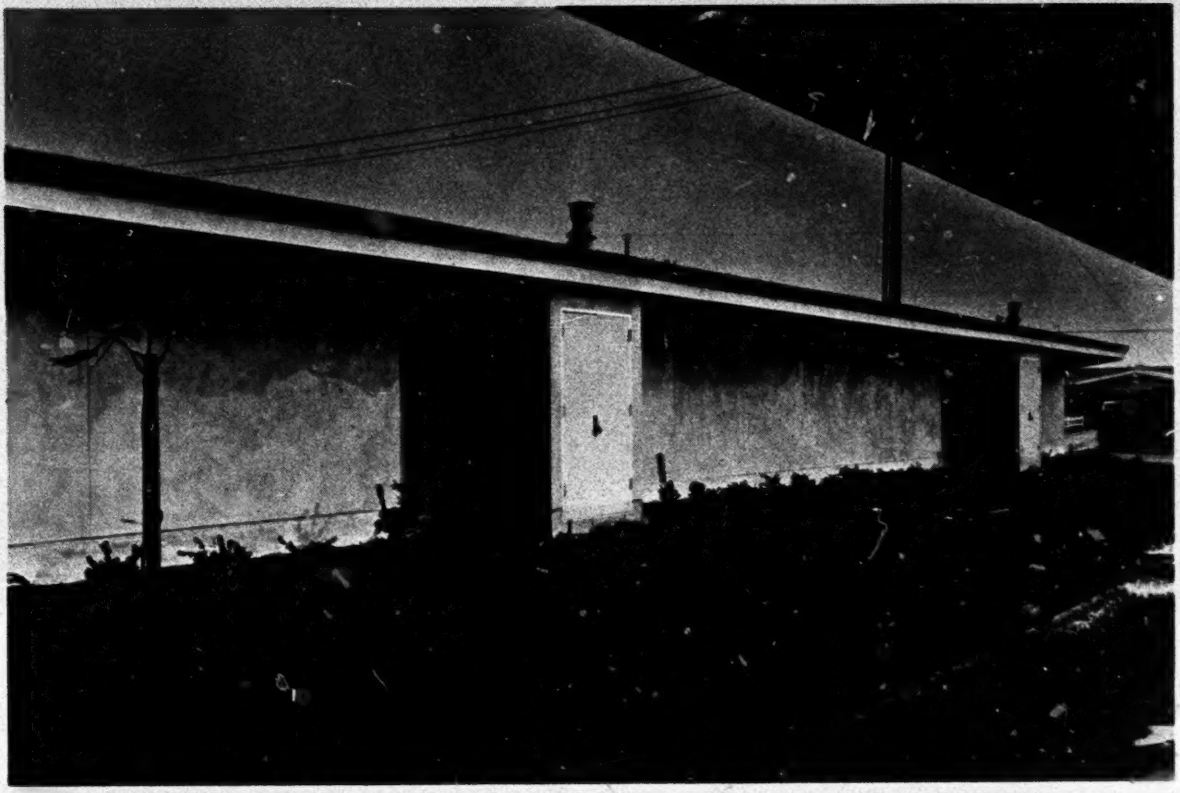
Layout of Test Facilities


Rooms and Associated Equipment:
Room A - Typhoon Heat Pump
Room B - Typhoon Heat Pump (Unit under test)
Room C - Arkla-Servel (Unit under test)
Room D - Arkla-Servel
A
B
C
D

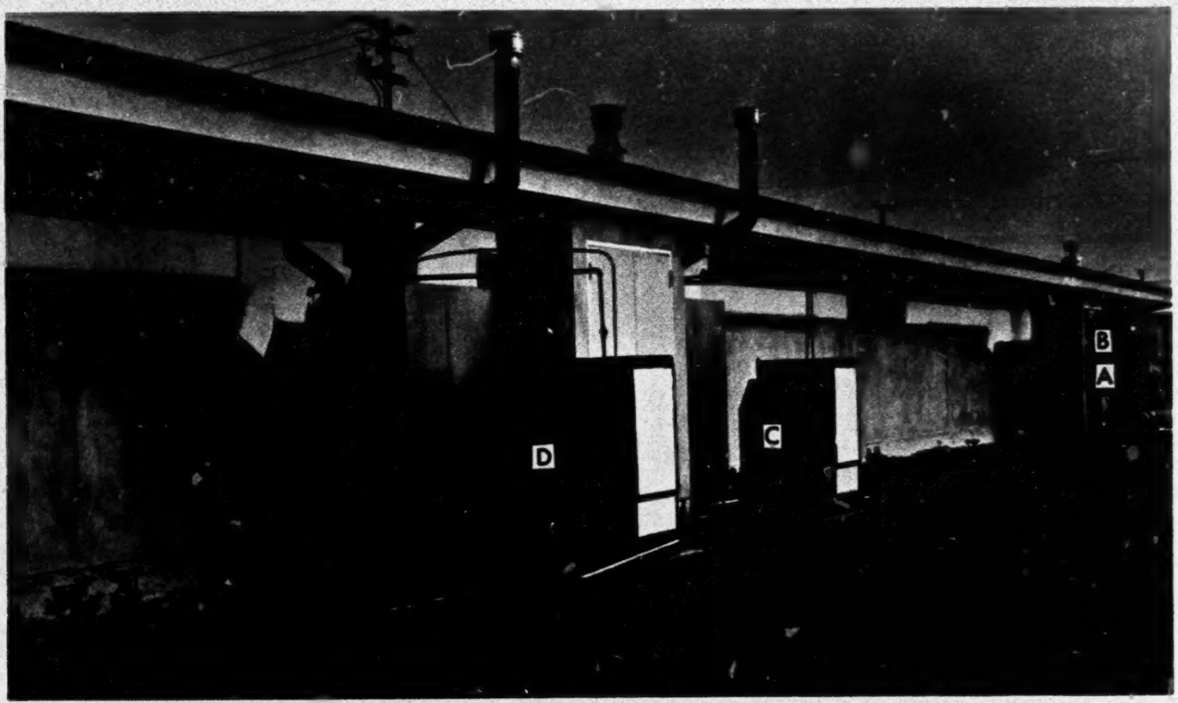
CLASSROOM BUILDING — EASTERN EXPOSURE



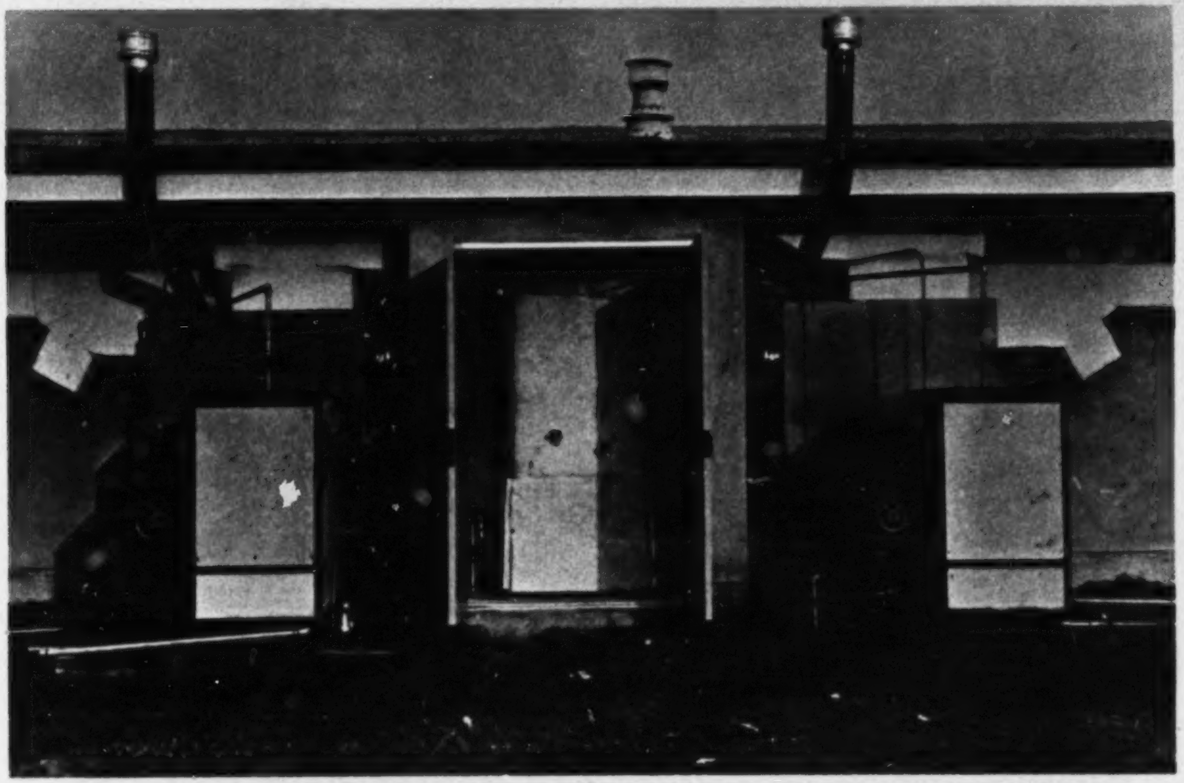
CLASSROOM BUILDING — SOUTHERN EXPOSURE
(northern exposure similar)



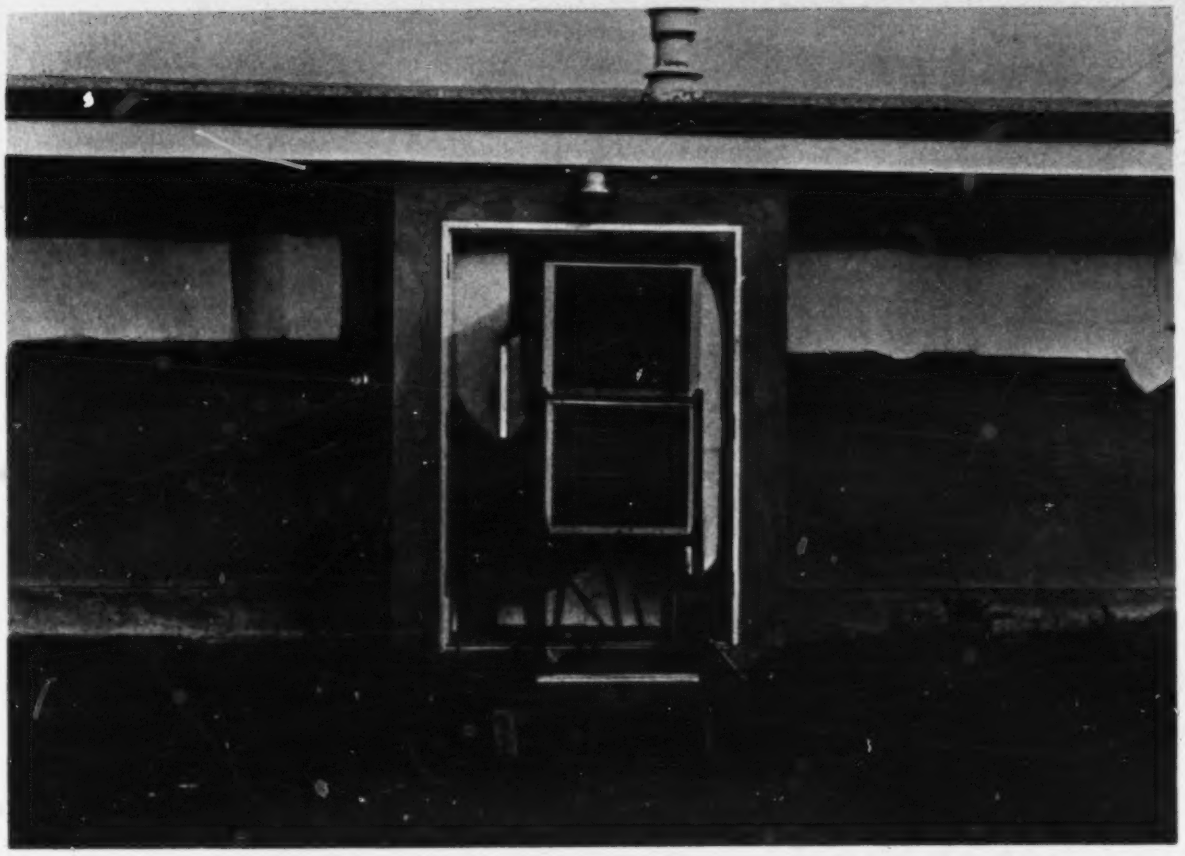
CLASSROOM BUILDING — WESTERN EXPOSURE
(before test units installed)



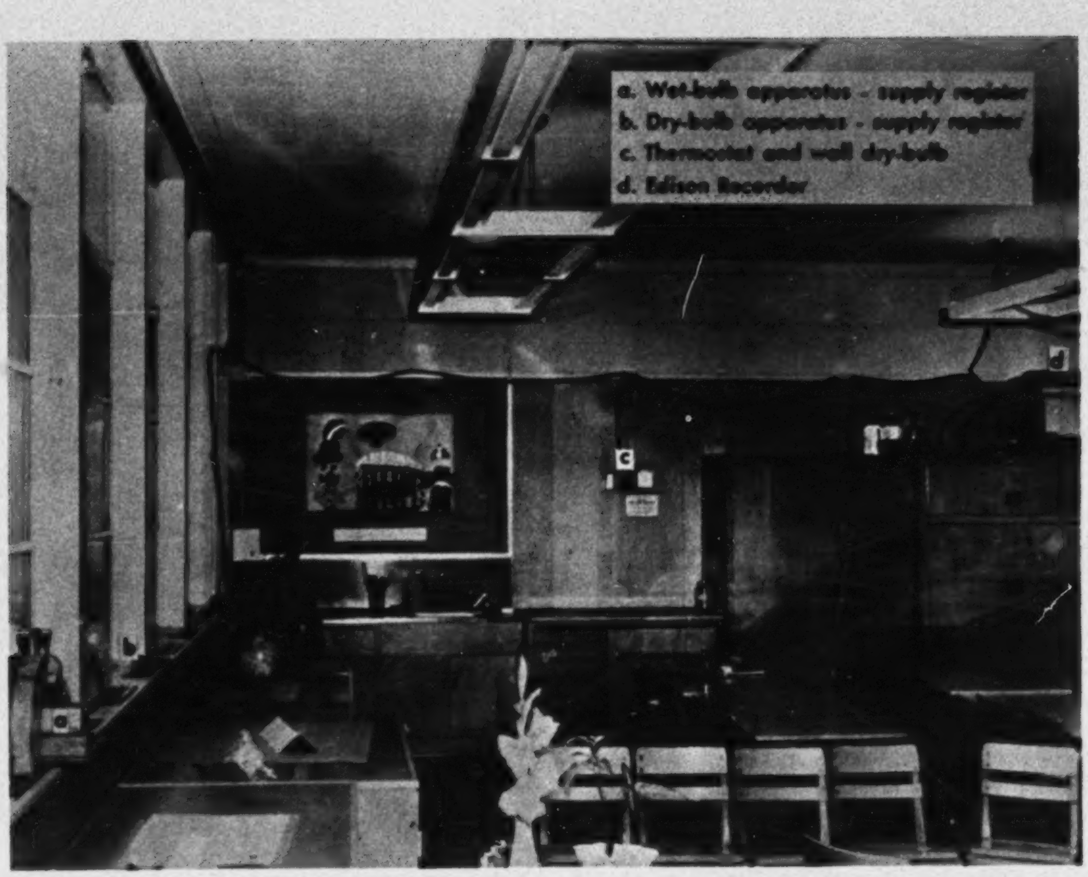
CLASSROOM BUILDING — WESTERN EXPOSURE
(after test units installed)
unit A — Typhoon heat pump
unit B — Typhoon heat pump (test unit)
unit C — Arkla-Servel (test unit)
unit D — Arkla-Servel



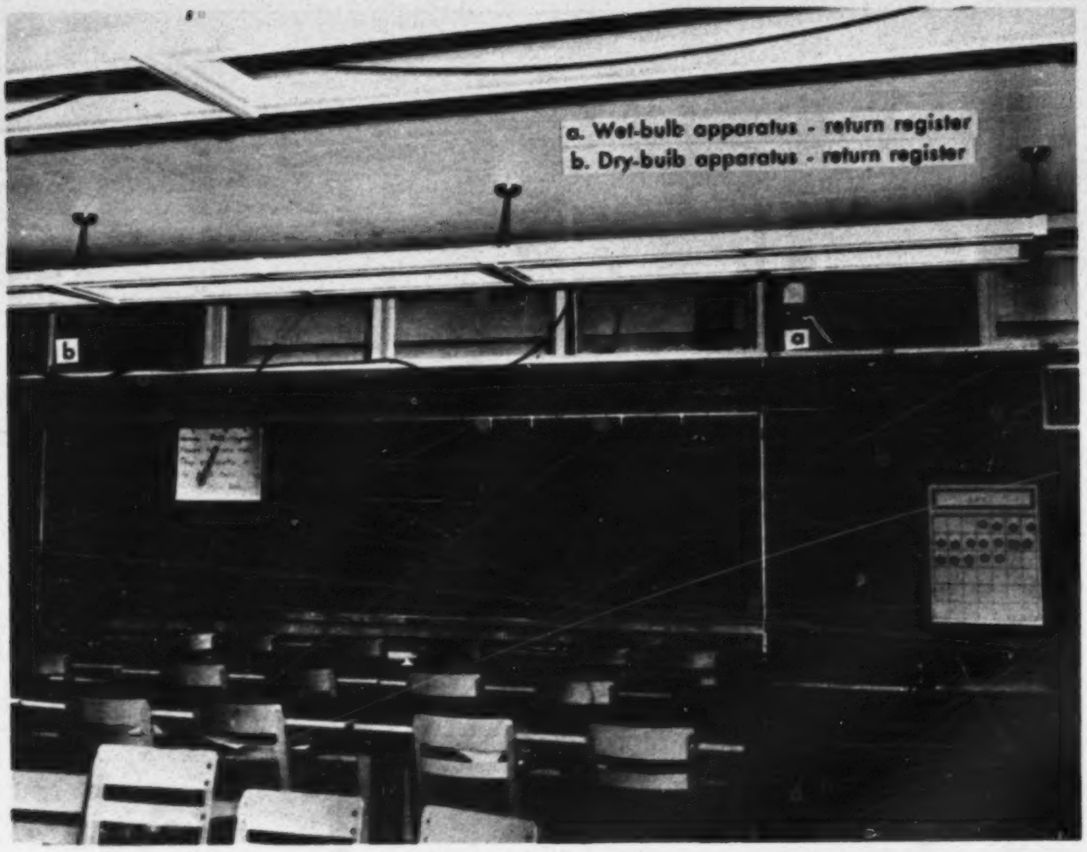
ARKLA-SERVEL INSTALLATION



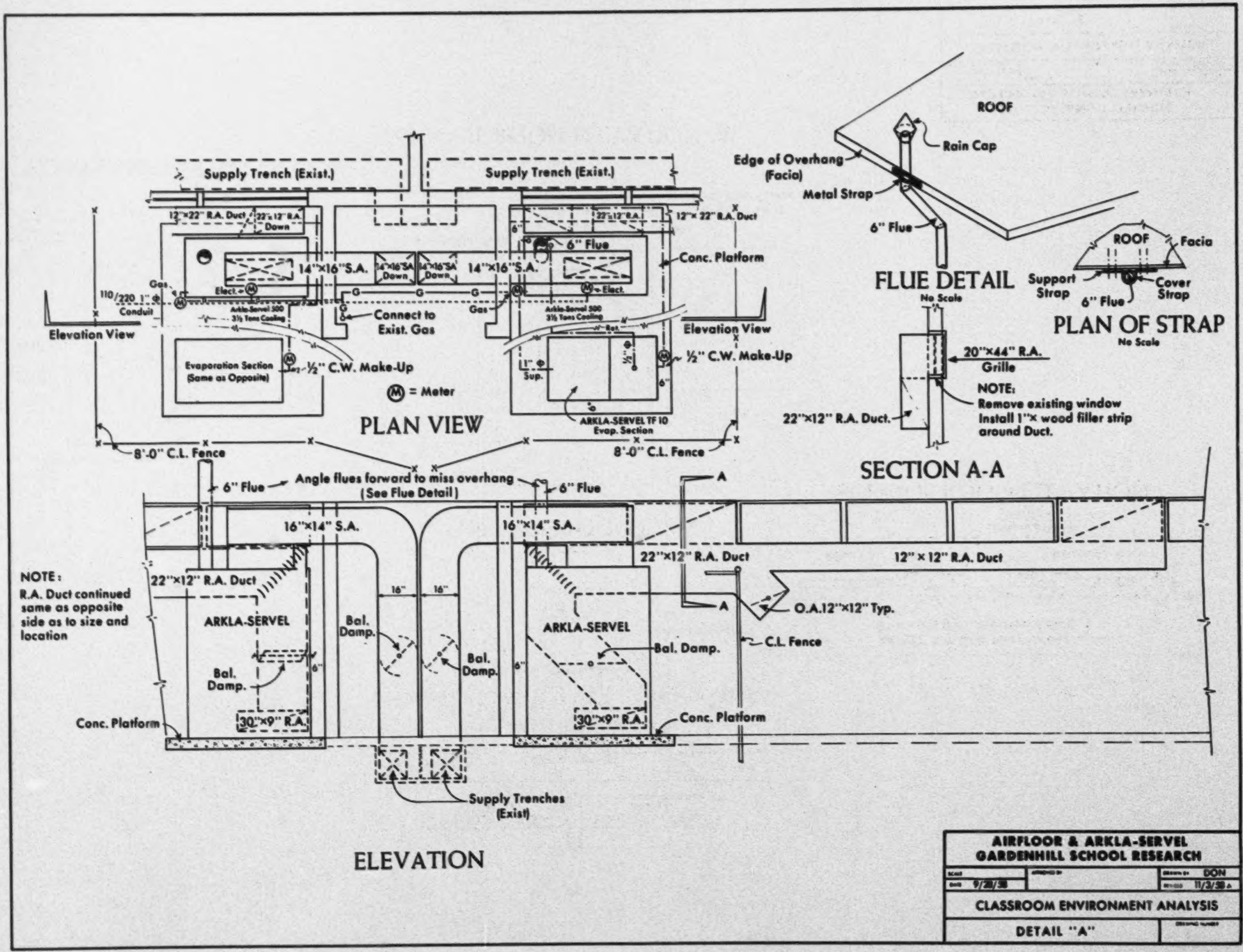
TYPHOON HEAT PUMP INSTALLATION

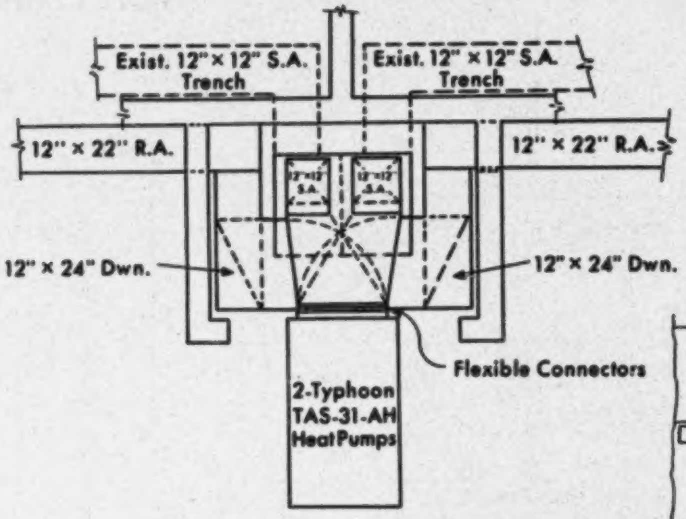

a. Wet-bulb apparatus - supply register
b. Dry-bulb apparatus - supply register
c. Thermostat and wall dry-bulb
d. Edison Recorder
d
c

CLASSROOM TYPHOON UNIT

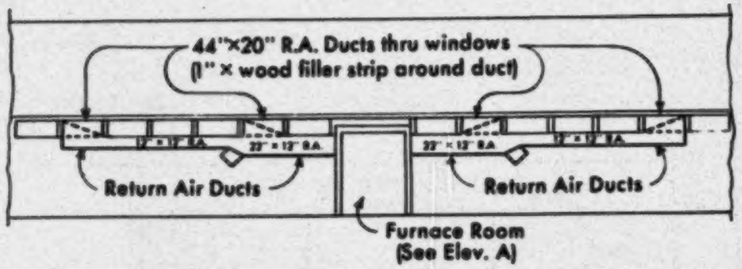

a. Wet-bulb apparatus - return register
b. Dry-bulb apparatus - return register
b
a

CLASSROOM TYPHOON UNIT

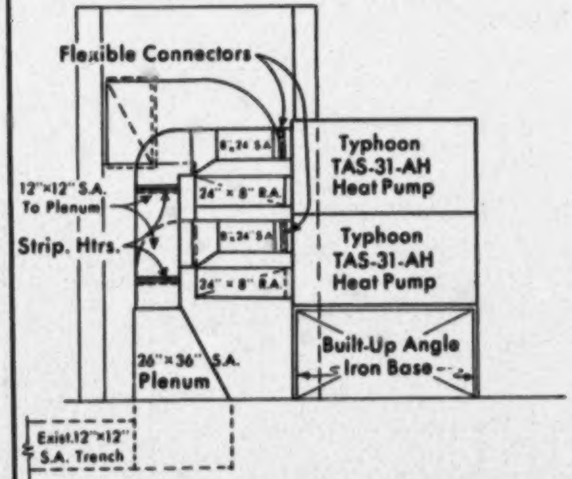

Supply Trench (Exist.)
Supply Trench (Exist.)
12"×22" R.A. Duct
22"×12" R.A. Down
22"×12" R.A.
12"×22" R.A. Duct
6" Flue
Conc. Platform
14"×16"S.A.
14"×16"SA Down
14"×16"SA Down
14"×16"S.A.
Gas
Elect.
Elect.
110/220 1" Φ Conduit
Arkla-Servel 500 3½ Tons Cooling
Arkla-Servel 500 3½ Tons Cooling
Connect to Exist. Gas
Gas
Elevation View
Elevation View
Evaporation Section (Same as Opposite)
½" C.W. Make-Up
½" C.W. Make-Up
1" Φ Sup.
Ⓜ = Meter
ARKLA-SERVEL TF 10 Evap. Section
PLAN VIEW
8'-0" C.L. Fence
8'-0" C.L. Fence
ROOF
Rain Cap
Edge of Overhang (Facia)
Metal Strap
6" Flue
FLUE DETAIL
No Scale
ROOF
Facia
Support Strap
6" Flue
Cover Strap
PLAN OF STRAP
No Scale
20"×44" R.A. Grille
NOTE: Remove existing window Install 1"× wood filler strip around Duct.
22"×12" R.A. Duct.
SECTION A-A
6" Flue
Angle flues forward to miss overhang (See Flue Detail)
6" Flue
A
A
16"×14" S.A.
16"×14" S.A.
22"×12" R.A. Duct
12" × 12" R.A. Duct
NOTE: R.A. Duct continued same as opposite side as to size and location
22"×12" R.A. Duct
ARKLA-SERVEL
ARKLA-SERVEL
16"
16"
Bal. Damp.
Bal. Damp.
Bal. Damp.
Bal. Damp.
6"
6"
6"
O.A.12"×12" Typ.
C.L. Fence
30"×9" R.A.
30"×9" R.A.
Conc. Platform
Conc. Platform
Supply Trenches (Exist)
ELEVATION
AIRFLOOR & ARKLA-SERVEL
GARDENHILL SCHOOL RESEARCH
DATE 9/28/58
DRAWN BY DON
REVISED 11/3/58 A
CLASSROOM ENVIRONMENT ANALYSIS
DETAIL "A"


Exist. 12" × 12" S.A. Trench
Exist. 12" × 12" S.A. Trench
12" × 22" R.A.
12" × 22" R.A.
12"×12" S.A.
12"×12" S.A.
12" × 24" Dwn.
12" × 24" Dwn.
Flexible Connectors
2-Typhoon TAS-31-AH HeatPumps

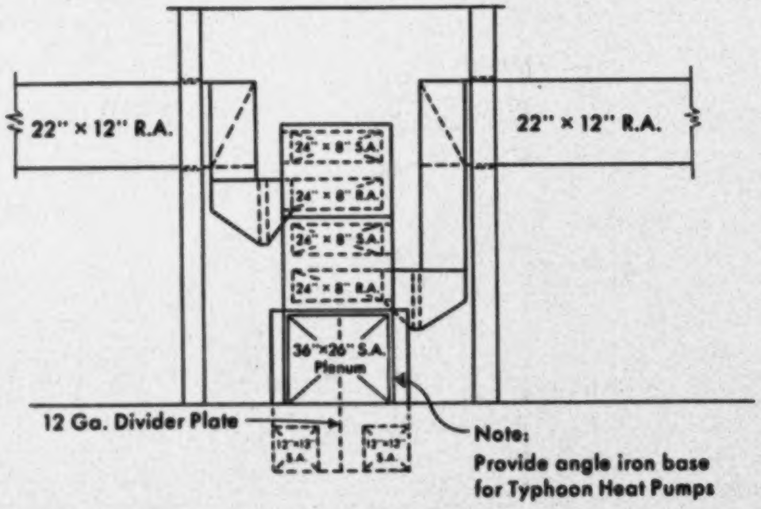
FURNACE ROOM PLAN


44"×20" R.A. Ducts thru windows (1" × wood filler strip around duct)
12" × 12" R.A.
22" × 12" R.A.
22" × 12" R.A.
12" × 12" R.A.
Return Air Ducts
Return Air Ducts
Furnace Room (See Elev. A)

SCHOOL ROOM ELEVATION


Flexible Connectors
8"×24" S.A.
24" × 8" R.A.
8"×24" S.A.
24" × 8" R.A.
12"×12" S.A. To Plenum
Strip. Htrs.
Typhoon TAS-31-AH Heat Pump
Typhoon TAS-31-AH Heat Pump
Built-Up Angle Iron Base
26"×36" S.A. Plenum
Exist.12"×12" S.A. Trench

EQUIPMENT SIDE ELEVATION


22" × 12" R.A.
22" × 12" R.A.
24" × 8" S.A.
24" × 8" R.A.
24" × 8" S.A.
24" × 8" R.A.
36"×26" S.A. Plenum
12 Ga. Divider Plate
12"×12" S.A.
12"×12" S.A.
Note:
Provide angle iron base for Typhoon Heat Pumps

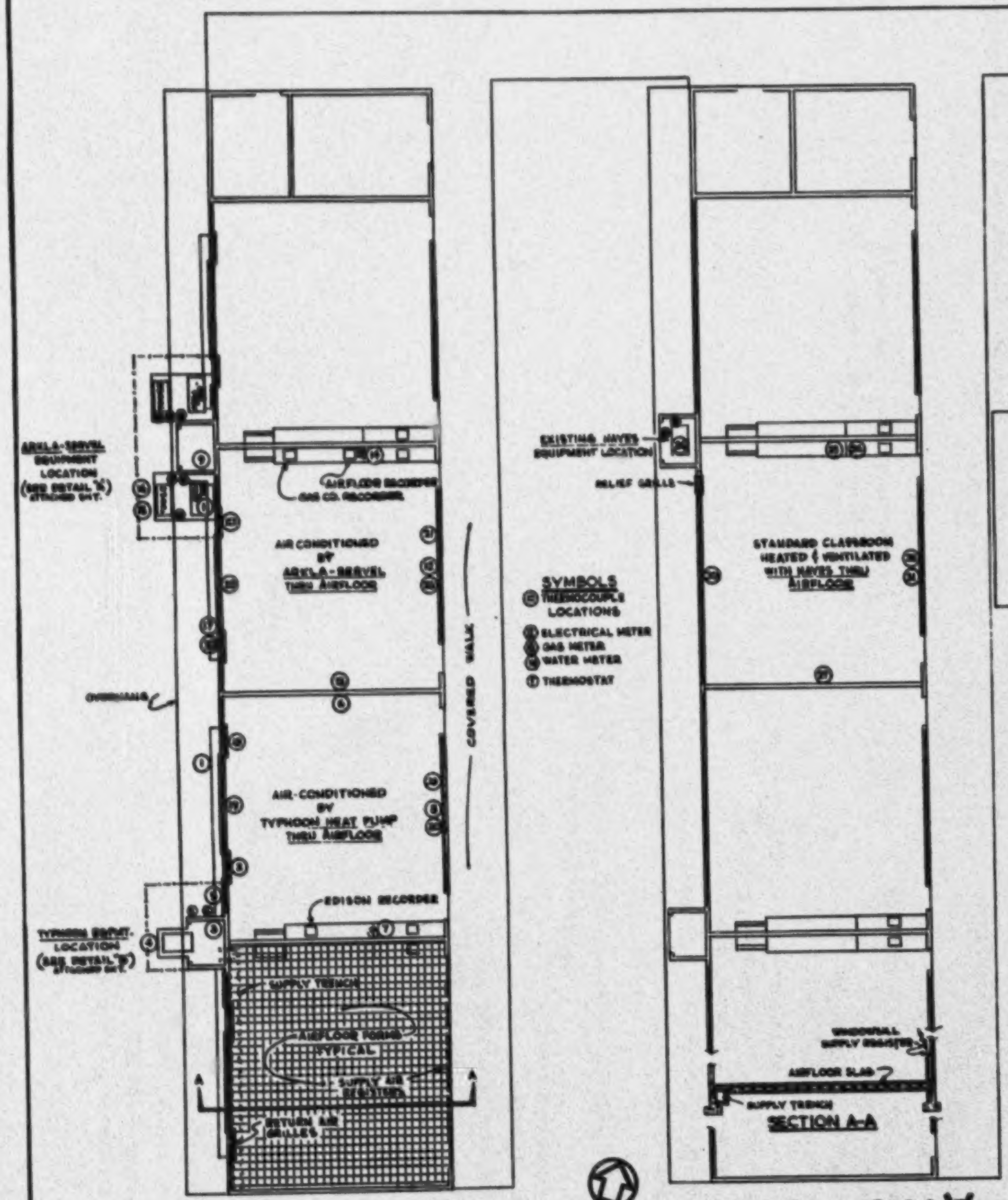
FURNACE ROOM ELEVATION "A"

AIRFLOOR AND TYPHOON
GARDENHILL SCHOOL RESEARCH

SCALE	APPROVED BY	DRAWN BY DON
DATE 9/28/58		REVISED 11/7/58

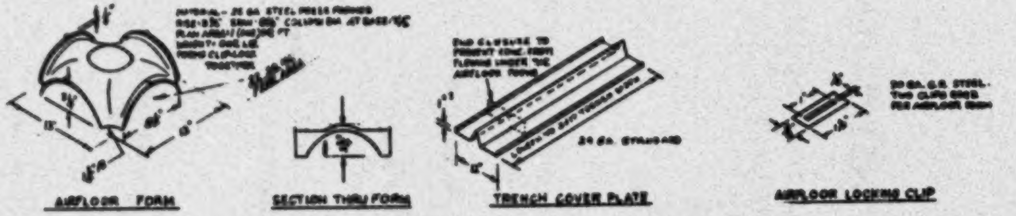
CLASSROOM ENVIRONMENT ANALYSIS

DETAIL "B"


ARKLA-SERVEL EQUIPMENT LOCATION (SEE DETAIL "X" ATTACHED SHT.)
AIRFLOOR RECORDER
GAS CO. RECORDER
AIR CONDITIONED BY ARKLA-SERVEL THRU AIRFLOOR
OVERHANG
AIR-CONDITIONED BY TYPHOON HEAT PUMP THRU AIRFLOOR
EDISON RECORDER
TYPHOON EQUIPT. LOCATION (SEE DETAIL "Y" ATTACHED SHT.)
SUPPLY TRENCH
AIRFLOOR FORMS TYPICAL
SUPPLY AIR REGISTER
RETURN AIR GRILLES
COVERED WALK
EXISTING HAYES EQUIPMENT LOCATION
RELIEF GRILLE
SYMBOLS
THERMOCOUPLE LOCATIONS
ELECTRICAL METER
GAS METER
WATER METER
THERMOSTAT
STANDARD CLASSROOM HEATED & VENTILATED WITH HAYES THRU AIRFLOOR
UNDERWALL SUPPLY REGISTER
AIRFLOOR SLAB
SUPPLY TRENCH
SECTION A-A
NORTH

FLOOR PLAN - BLDG. "G"

FLOOR PLAN - BLDG. "F"


MATERIAL - 26 GA. STEEL PRESS FORMED
AIRFLOOR FORM
SECTION THRU FORM
END CLOSURE TO PREVENT CONC. FROM FLOWING UNDER THE AIRFLOOR FORMS
24 GA. STANDARD
TRENCH COVER PLATE
20 GA. G.S. STEEL. TWO CLIPS REQ'D PER AIRFLOOR FORM
AIRFLOOR LOCKING CLIP

C O N T R I B U T O R S

SUPERVISION – ENGINEERING – COORDINATION by KW KISTNER, WRIGHT & WRIGHT

EDISON CO. RECORDER
LEEDS-NORTHRUP POTENTIOMETER

COUPLE LOCATION	DESIGNATION OF TEMP. RECORDED	D.B. / W.B.	TERM NO.	ROOM OF LOCATION
①	OUTSIDE AIR	D.B.	1	TYPHOON
②	RETURN AIR	D.B.	2	"
③	DISCHARGE AIR	D.B.	3	"
④	EXHAUST AIR	D.B.	4	"
⑤	MIXED AIR	D.B.	5	"
⑥	ROOM - OPPOSITE	D.B.	6	"
⑦	ROOM - "	D.B.	7	"
⑧	REGISTER AIR	D.B.	8	"

GAS CO. RECORDER
HONEYWELL-BROWN POTENTIOMETER

COUPLE LOCATION	DESIGNATION OF TEMP. RECORDED	D.B. / W.B.	TERM NO.	ROOM OF LOCATION
⑨	DISCHARGE AIR	D.B.	1	ARKLA-SERVEL
⑩	RETURN AIR	D.B.	3	" "
⑪	MIXED AIR	D.B.	5	" "
⑫	REGISTER AIR	D.B.	7	" "
⑬	ROOM - OPPOSITE	D.B.	9	" "
⑭	ROOM - "	D.B.	11	" "
⑮	WATER INLET - TOWER	D.B.	13	" "
⑯	WATER OUTLET - TOWER	D.B.	15	" "

AIRFLOOR RECORDER
HONEYWELL-BROWN POTENTIOMETER

COUPLE LOCATION	DESIGNATION OF TEMP. RECORDED	D.B. / W.B.	TERM NO.	ROOM OF LOCATION
⑰	OUTSIDE AIR	W.B.	1	ARKLA-SERVEL
⑱	RETURN AIR TEMP	W.B.	2	TYPHOON
⑲	FLOOR @ TRENCH	D.B.	3	"
⑳	FLOOR @ REGISTER	D.B.	4	"
㉑	SUPPLY AIR TEMP	W.B.	5	ARKLA-SERVEL
㉒	FLOOR @ TRENCH	D.B.	6	" "
㉓	FLOOR @ REGISTER	D.B.	7	" "
㉔	DISCHARGE AIR	D.B.	8	HAYES
㉕	ROOM @	W.B.	9	"
㉖	ROOM @	D.B.	10	"
㉗	ROOM OPPOSITE	D.B.	11	"
㉘	REGISTER AIR	D.B.	12	"
㉙	SUPPLY AIR TEMP	W.B.	13	TYPHOON
㉚	FLOOR @ TRENCH	D.B.	14	HAYES
㉛	FLOOR @ REGISTER	D.B.	15	"
㉜	RETURN AIR TEMP	W.B.	16	ARKLA-SERVEL

GARDENHILL SCHOOL
HEFLIN & GARDENHILL ST.
LA MIRADA, CALIFORNIA
NORWALK LA MIRADA SCHOOL DIST.

MASTER PLOT PLAN

CLASSROOM ENVIRONMENT ANALYSIS!

METERING EQUIPMENT

TYPHOON HEAT PUMP
- Electric meter — kilowatt-hours
  - Southern California Edison Company — #7-560642

ARKLA-SERVEL AIR CONDITIONER
- Electric meter — kilowatt-hours
  - Southen California Edison Company — #7-560621
- Gas meter — cubic feet
  - Southen California Gas Company — #2052146
- Water meter — cubic feet
  - Neptune meter — Trident 3/4
  - #14339051

HAYES GAS FIRED FURNACE
- Electric meter — kilowatt-hours
  - Southern California Edison Company — #7-560491
- Gas meter — cubic feet
  - Southern California Gas Company — #2048085

TEST EQUIPMENT

TYPHOON HEAT PUMP — Model TAS 31 AH with supplemental heater
- Motor compressor — 3 1/2 HP
- Thermostat — Automatic 2 stage
- Supply Fan rated capacity — Up to 1600 cfm
- Capacity cooling* — 35,000 Btu/hr
- Capacity heating** — 52,000 Btu/hr
- Supplemental electric heater — 5 KW, single stage
- Supply fan motor — 1/3 HP; Condenser fan motor — 1/4 HP
- * — Based on 95°F. air condenser and air entering evaporator @ 80°F. d.b., 67°F. w.b.
- ** — Based on 70°F. return air, 45°F. outside air. Capacity includes supplemental heater rating.

ARKLA—SERVEL AIR CONDITIONER — Model 500, Evaporative Cooler Model TF-10
- Thermostat: Automatic, 1 stage
- Blower: Motor — 1/3 HP
  - Rated quantity cooling — 1400 cfm
  - Maximum quantity cooling — 1700 cfm
- Refrigerating capacity*— 42,000 Btu/hr
- Heating capacity — 96,000 Btu/hr
- Supply Fan Motor — 1/3 HP; Pump Motor 1/4 HP
  - *— Based on inlet water of 75°F. 444 gph, 1400 cfm, inlet air 80°F. d.b., 67°F. w.b.

HAYES GAS FIRED FURNACE — Model number 210, SED-CF
- Maximum air, thru-put — 2560 cfm
- Minimum air, thru-put — 1920 cfm
- Btu per hour input — 210,000
- Btu per hour output — 168,000
- Single stage gas inlet — split manifold

RECORDING INSTRUMENTS

TEMPERATURE RECORDER (Supplied by the Edison Company)
- LEEDS-NORTHRUP POTENTIOMETER
  - Catalogue number 61358
  - Serial number 58-724-3
  - Range 20° — 120°F.
  - Volts 115, Amps 1.5
  - Chart number 312

TEMPERATURE RECORDER (Supplied by the Gas Company)
- HONEYWELL-BROWN POTENTIOMETER
  - Model 153X60P16-X-31
  - Serial number 500985, So. Cal. Gas Co. #33800
  - Range 0° — 150°F.
  - Volts 115, Amps 0.55, Watts 55
  - Chart number 519

TEMPERATURE RECORDER (Supplied by Airfloor, Inc.)
- HONEYWELL-BROWN POTENTIOMETER
  - Model 153X60P16-X-31
  - Serial number 633170
  - Range 0° — 200°F.
  - Volts 115, Amps 0.55, Watts 55
  - Chart number 519

WET-BULB APPARATUS
- Designed-Produced by Airfloor, Inc.
- Calibrated using Fisher Scientific instrument - Psychrometer Model 568

AIR METERING EQUIPMENT
- Paddle type Bachrach flow meter
- Alnore Velometer - 3200 series

Utility Consumption and Hours of Operation

Utility Consumption and Hours of Operation

The table on page 26 shows the hours the units operated on the cooling and heating cycles and the energy consumed, both on a monthly basis. The Typhoon Heat Pump unit and the Arkla-Servel unit were controlled by seven day time clocks and were not permitted to operate from 4:00 pm Friday to 4:00 am Monday. The Hayes Furnace unit operation varied during the year. During most of the winter months it was operational continuously, while during the summer there were periods when it was shut down. This explains the fact that the Hayes unit consumed more gas than the Arkla unit for the months of December, January, and February, for during these colder months a good part of the weekends required heating in the rooms. During this period, solely the weekend operation of the Hayes unit resulted in greater gas consumption than that portion of gas consumed by the Arkla unit during the week while operating on the cooling cycle. Except where noted, the averages in the following tables are based upon operation from May 1, 1959 to May 31, 1960. The months of partial operation, April, 1959 and June, 1960, have not been included.

UTILITY CONSUMPTIONS

	AVERAGE	MAXIMUM	MINIMUM
TYPHOON HEAT PUMP UNIT			
ELECTRICITY	1141 kw-hrs	1,401 kw-hrs	787 kw-hrs
ARKLA-SERVEL ABSORPTION UNIT			
ELECTRICITY	305 kw-hrs	374 kw-hrs	229 kw-hrs
GAS	14,800 cu.ft.	19,300 cu.ft.	9,900 cu.ft.
WATER	174 cu.ft.	257 cu.ft.	47 cu.ft.
HAYES FURNACE UNIT			
ELECTRICITY	363 kw-hrs	470 kw-hrs	261 kw-hrs
GAS	8700 cu.ft.	21,400 cu.ft.	300 cu.ft.

The average monthly time of operation of the Arkla unit was 167 hours of which 122 hours were cooling and the remainder, 45 hours, was in heating. For the Arkla unit, the minimum time of cooling for any month was 41 hours. The Typhoon unit averaged 307 hours of operation monthly; 164 hours of this time was in cooling and 143 hours in heating on the average. The second stage compressor was in operation approximately 30% of the operating time. Most of the heating was done as first stage heating. Of the second stage heating that did occur, the major portion came on Monday morning when, after having the units shut down for the weekends, the rooms dropped in temperature below 68°F. Very seldom was second stage heating required during the week. During this fourteen-month period, no use was made of the supplemental electric heater in the Typhoon unit even though on January 1, 1960, when no classes were in session, the outside temperature dipped to 38°F.

On pages 29 and 30 there is a plot of the total number of hours cooling for a weekly period against the average of the daily high temperatures for that week. Each point that is plotted is identified by the corresponding average of the low temperatures for the same weekly period. The general trend indicates less cooling was required for lower nighttime temperatures due to the pre-cooling of the concrete slab. However, when a great deal of heating had taken place, the cooling cycle had to overcome the "inertia" effect of the slab and a greater amount of cooling was required. The relationship of less hours cooling to lower nighttime temperatures for a given high temperature was held to more closely by the Arkla-Servel unit. This was due to the fact that the discharge temperature from this unit was higher than with the first stage operating on the heat pump. Thus, room design temperature was obtained more quickly in the Arkla room and the slab picked up less energy than the slab of the Typhoon room even though the circulating air in the Arkla case was a higher mean temperature, which is readily seen in looking at the discharge temperature charts. These graphs show the off-on cycling of the Arkla unit when on heating in contrast to the more continual operation of the Typhoon unit. The result was that the Arkla unit had less slab "inertia" effect to overcome and hence its hours of cooling were more directly related to the nighttime low temperatures.

It is significant to note that the maximum energy consumed in both units for a one month period came in a month in which the average of the daily high temperatures were nearly the average daily high temperatures for the year. In the case of the Typhoon unit, this occurred in March, 1960 with the Arkla unit maximum consumption occurring in March and May, 1960. The effect of units cycling with an Airfloor distribution system is seen in looking at the month of coldest weather, January, 1960, which resulted in energy consumption rates for both units at about the average rate for the year. This was also true for the months of warmest weather during which classes were in full-time session, September and October. August, during which month classes were held only until 12:00 noon, had an average high temperature of 87°F. and the consumption for the Arkla unit was above average monthly consumption, but the Typhoon was a little below.

The demands in the following table were measured at different intervals during the test. In tables B and C on pages 27 and 28 these demands are used to compute the energy consumptions and these are, in turn, correlated against metered consumption. It is seen that the gas demands of the Arkla Unit were nearly constant during both heating and cooling while the electricity demand varied. In the analysis of the Typhoon Unit, the energy consumed during first stage operation was computed by assuming the ratio of the number of hours of first stage cooling to first stage heating, was the same as the ratio of total hours cooling to heating. The instrumentation did not permit distinguishing between the relative hours of heating and cooling when operating on either the first stage or operating on the second stage. The effect of the outside temperature on the electrical consumption of the Typhoon heat pump was to increase the demand as the temperature increased; the demand on second stage cooling reaching 5.4 kilowatts with an outside temperature of 95°F.

The variance between the computed and the metered consumption can be attributed to several items. The units were governed by seven-day, twenty-four hour time clocks, hence, it was necessary to perform an on-off operation on Saturday and Sunday of each week. Practically, this resulted in from three to four hours of operation on the weekends and this was not accounted for in the analysis. Further, with the metered data it was necessary to interpolate the weekly data to determine the meter reading that occurred on the last day of the month.

It is not possible to determine the ton-hours of cooling per month for the Typhoon Unit because the percentage of each of the stages operating during the cooling cycle was not metered. However, for the Arkla Unit the ton-hours of cooling per month based upon *rated cooling capacity* were as follows:

TON-HOURS OF COOLING PER MONTH BASED UPON RATED COOLING CAPACITY

ARKLA—SERVEL ABSORPTION UNIT

MONTH	TON-HOURS	TON-DAYS
April 9-30 April 9-30, 1959	263	11.0
May	287	12.0
June	598	24.9
July	525	21.9
August	725	30.2
September	539	22.4
October	458	19.1
November	336	14.0
December	178	7.32
January, 1960	143	5.95
February	214	8.91
March	458	19.1
April	350	14.6
May	665	27.7
June 1- 7, 1960	434	18.1

DEMAND RATES

TYPHOON HEAT PUMP UNIT

Cooling: First stage operation	2.4 - 2.6 kw
First and second operation	5.2 - 5.4 kw
Heating: First stage operation	2.3 kw
First and second operation	4.4 - 4.7 kw
Air circulation: Air circulation only	540 watts

ARKLA SERVEL ABSORPTION UNIT

Cooling: Gas	80 cubic feet per hour
Electricity	1.4 kw
Water	1.4 cubic feet per hour
Heating: Gas	110 cubic feet per hour
Electricity	380 watts
Air circulation: Air circulation	380 watts

TABLE A

METERED DATA

DATE	TYPHOON HEAT PUMP			ARKLA - SERVEL					HAYES FURNACE		
	Electricity Consumptions kw-hrs	Cooling Time Hours	Heating Time Hours	Electricity Consumption kw-hrs	Gas Consumption cu.ft.	Water Consumption cu.ft.	Cooling Time Hours	Heating Time Hours	Electricity Consumption per Room	Gas Consumption per Room	Heating Time Hours
April 9-30 1959	700	88	53	201	8,300	114	79	15	197	4,000	27
May	1,006	131	89	263	9,900	116	82	28	277	5,300	34
June	912	106	44	353	16,000	257	171	18	310	2,000	7
July	1,046	301	0	368	16,300	308	199	3	287	0	0
August	1,055	280	0	374	16,600	310	207	0	278	300	0
September	889	215	0	338	13,900	241	154	13	284	1,700	3
October	967	139	36	318	13,500	207	131	26	369	4,800	24
November	1,267	156	195	271	13,900	135	96	56	364	9,800	81
December	1,171	72	250	229	13,200	77	51	83	394	16,900	161
January 1960	1,313	107	312	232	14,700	47	41	105	375	21,400	221
February	1,296	131	280	238	14,000	72	61	83	434	19,000	172
March	1,401	175	270	309	18,300	158	131	73	470	15,100	127
April	1,231	182	194	299	13,500	-	100*	50*	422	10,000	75
May	1,283	209	149	363	19,300	-	190	46	456	7,300	51
June (1-17) 1960	559	112	44	217	11,900	-	124	22	247	2,400	2
Average 5/1/59-5/31/60	1,141	164	143	305	14,800	174	126	44	363	8,700	74

* Estimated Data

TABLE B

ENERGY CONSUMPTION ANALYSIS OF TYPHOON HEAT PUMP

DATE	Total Hours of Unit Operation	Cooling		Heating		First Stage Operation Hours only (add)	First & Second Stage Operation Hours	Air Circulation Only Hours	Computed Electrical Consumption				Metered Consumption kw-hrs	Percent Error *
		Hours	Percent of Heating Plus Cooling	Hours	Percent of Heating Plus Cooling				First Stage kw-hrs	First & Second Stages kw-hrs	Circulation kw-hrs	Total		
April 9-30 1959	324	88	62%	53	38%	51	90	183	127	459	99	685	700	2.1%
May	448	148	59%	104**	41%	153	99	196	378	504*	106	988*	1006	1.8%
June	476	216	99%	2	1%	162	56	258	436	302	139	877	912	3.8%
July	496	301	100%	0	0%	267	34	195	695	184	105	984	1,046	5.9%
August	452	280	100%	0	0%	215	65	172	560	352	93	1,005	1055	5.0%
September	480	215	100%	0	0%	164	51	265	417	275	143	835	889	6.1%
October	472	130	77%	39	23%	7	162	303	18	842	164	1,024	967	5.9%
November	452	156	44%	195	56%	223	128	101	545	635	55	1,235	1267	2.5%
December	504	72	22%	250	78%	276	46	182	667	220	98	985	1171	16.0%
January 1960	448	107	26%	312	74%	319	100	29	762	482	17	1,261	1313	4.0%
February	452	131	32%	280	68%	311	100	41	748	486	22	1,256	1296	3.1%
March	504	175	39%	270	61%	340	105	59	829	515	32	1,376	1401	1.8%
April	448	182	48%	194	52%	286	90	72	700	450	39	1,189	1231	3.4%
May	476	209	58%	149	42%	244	114	118	590	578	64	1,232	1283	4.0%
June 1-17 1960	280	112	72%	44	28%	126	30	124	316	156	67	539	559	3.6%

* Metered data used as base
** Includes 26 hours - 2nd stage heating when change-over valve locked.

ENERGY CONSUMPTION ANALYSIS OF ARKLA SERVEL UNIT

TABLE C

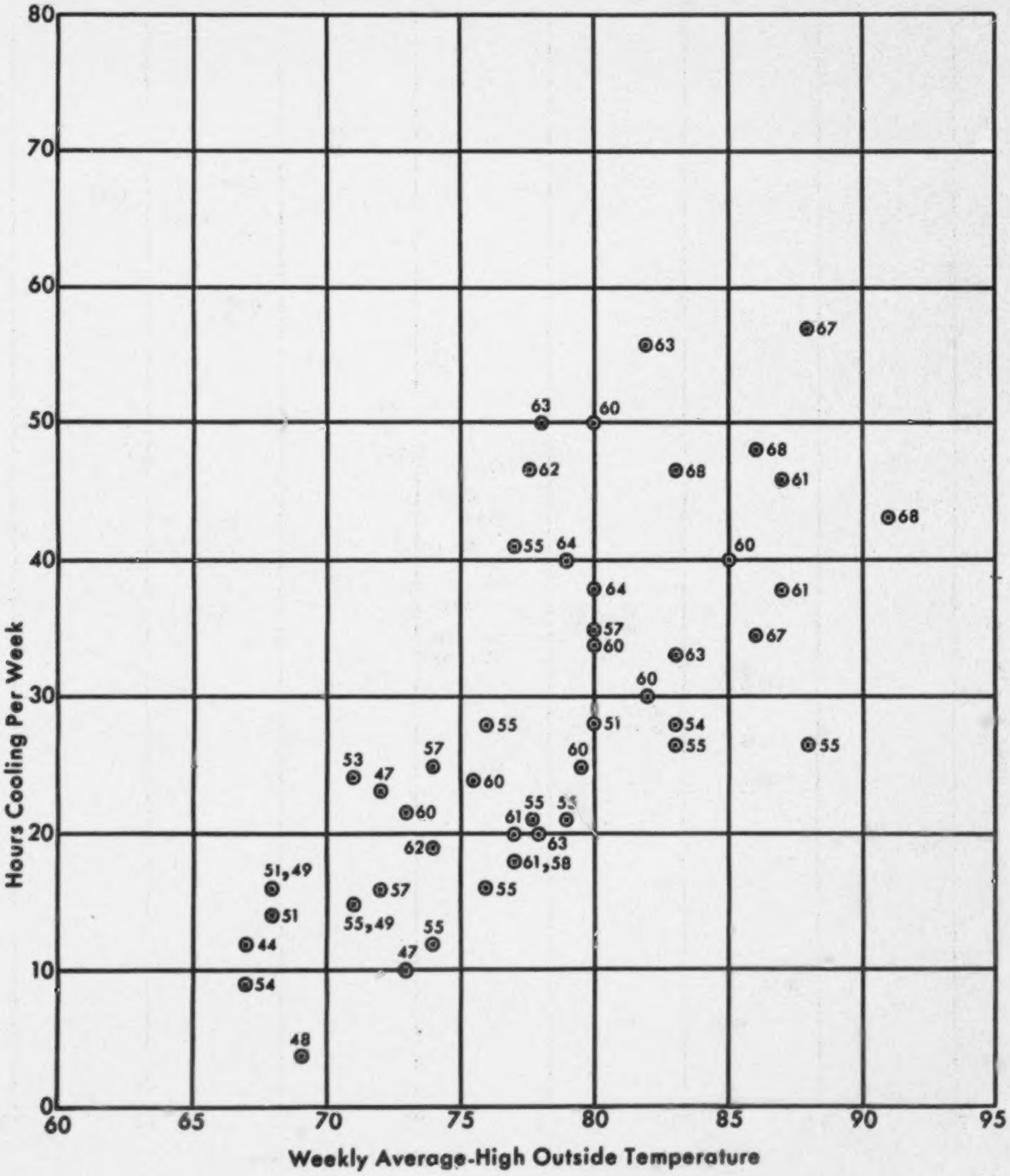
Date	Total Hours of Unit Operation	Cooling		Heating		Air Circulation Only - Hrs	Computed Consumptions								Percent Error From Metered Data **	
							Electricity - kw - hrs				Gas - cubic feet			Water		
		Hours	Percent Htng & Cool.	Hours	Percent Htng & Cool.		Cooling	Heating	Circulation	Total	Cooling	Heating	Total	Total cu.ft.	Electricity	Gas
April 9-30 1959	324	79	84%	15	16%	230	111	5	87	203	6,300	1,700	8,000	114	1.0%	3.8%
May	448	82	74%	28	26%	338	115	9	128	252	6,600	3,100	9,700	116	4.2%	2.0%
June	476	171	91%	18	9%	287	240	6	117	363	13,700	2,000	15,700	257	2.8%	1.9%
July	496	199	99%	3	1%	294	279	1	112	392	15,900	300	16,200	280	6.5%	0.6%
August	452	207	100%	0	0%	245	290	0	93	383	16,600	0	16,600	310	2.4%	0.0%
September	480	154	92%	13	8%	313	215	4	119	338	12,300	1,400	13,700	241	0.0%	1.4%
October	273	131	84%	26	16%	315	183	8	120	311	10,500	2,900	13,400	207	2.2%	0.7%
November	452	96	63%	56	37%	300	134	18	114	266	7,700	6,200	13,900	135	1.8%	0.0%
December	504	51	38%	83	62%	370	71	27	141	239	4,100	9,200	13,300	77	4.3%	0.8%
January 1960	448	41	28%	105	72%	302	57	34	115	206	3,300	11,600	14,900	47	11.0%	1.3%
February	452	61	42%	83	58%	308	85	22	117	224	4,900	9,200	14,100	72	5.9%	0.7%
March	504	131	64%	73	36%	300	183	23	114	320	10,500	8,000	18,500	158	3.6%	1.1%
April*	448	100*	69%	50*	31%	288	154	16	109	279	8,000	5,500	13,300	-	6.7%	1.5%
May	476	190	81%	46	19%	240	266	15	91	372	15,200	5,100	20,300	-	2.5%	5.0%
June 1-17 1960	280	124	85%	22	15%	134	174	7	51	232	10,000	2,000	12,900	-	6.9%	4.2%

*Estimated Data
**Metered data used as base

ARKLA-SERVEL ROOM

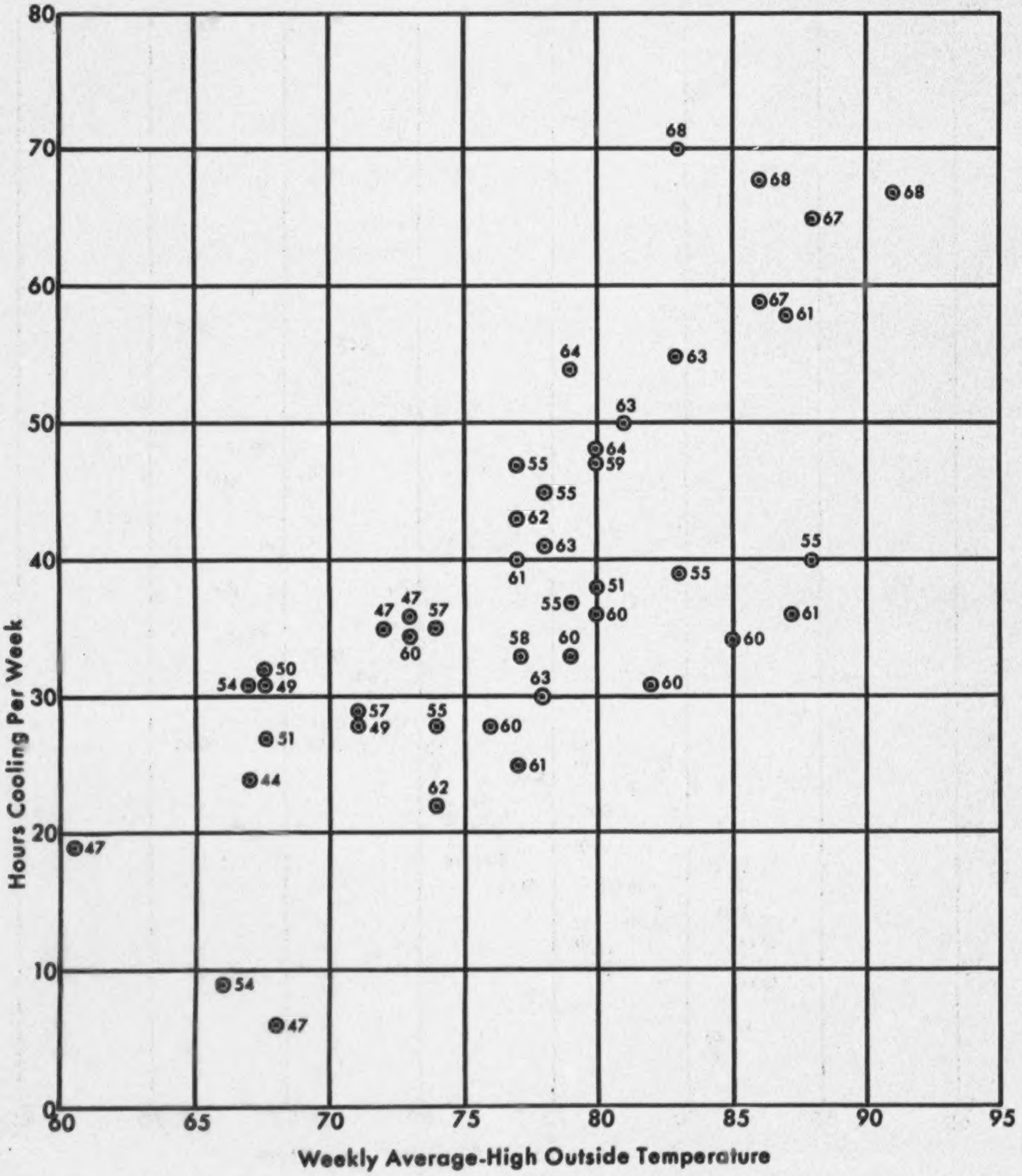
HOURS COOLING VERSUS WEEKLY AVERAGE HIGH OUTSIDE TEMPERATURE

WITH WEEKLY AVERAGE LOW OUTSIDE TEMPERATURE AS PARAMETER



TYPHOON ROOM

HOURS COOLING VERSUS WEEKLY AVERAGE HIGH OUTSIDE TEMPERATURE WITH WEEKLY AVERAGE LOW OUTSIDE TEMPERATURE AS PARAMETER



Thermal Environment

Thermal Environment

The print on page 19 and the photographs on page 16 show the apparatus and technique of determining the wet and dry bulb temperatures and those locations where the temperatures were recorded. The temperatures recorded on the Brown Recorder were measured with thermocouples, whereas the Leeds Recorder used a resistance pickup.

The heat pump and absorption units were not operated from 4:00 pm each Friday to 4:00 am the following Monday. Thus at certain times of the year, the room temperature reached extreme values during the weekend periods. The wet bulb temperatures reached abnormally high values during the weekend periods, since without the units operating no air was blown across the supply-air wet bulb apparatus. These temperatures have been excluded in determining the monthly means as shown in Table D on page 35.

At the beginning of the test, room thermostats were calibrated and set with limits of 67°F. and 73°F. In October, 1959 the thermostat in the heat pump room was reset to 68°F. — 72°F. and in the absorption room the setting was changed to 68°F. — 73°F. During the first week in May, 1960, the thermostats were again reset. The range on the heat pump room thermostat was dropped to 67°F. — 71°F. and the absorption room thermostat was reset with 68°F.—72°F. limits. This last change was made inasmuch as the units were not going on the cooling cycle until the room temperature reached 74°F. — 76°F.

The variation in temperatures at various locations is shown by temperature graphs. On pages 37 to 54 are temperature graphs for a series of days having a daily range in outside temperatures of 48°F. — 57°F. up to a daily range of 56°F. — 96°F. These graphs are arranged in order of increasing daily maximum temperatures. Each set of graphs includes outside and room dry-bulb and wet-bulb temperatures, floor temperatures, unit discharge temperature, and supply air temperature.

The room temperatures were recorded at locations adjacent to the room thermostat and also near walls that were located opposite to the thermostat. There were very few occasions where these two temperatures differed more than two degrees, generally having a difference of less than one degree.

Since the Airfloor distribution system has very high energy storage capacity, and due to the fact that 20% fresh air was circulated in the absorption and heat pump rooms, it becomes impossible to set an outside temperature at which heating or cooling would take place. Generally it was necessary for the outside temperature to pass below 60°F. before heating was required even though this temperature in itself was not sufficient to cause heating. A further requirement was the rate at which the outside temperature changed. A low of 55°F. was recorded without the heating cycle operating because the drop to 55°F. was sudden and the slab had sufficient energy stored to temper the air and maintain a room temperature of 68°F. If the heating cycle was not on when classes began in the morning, then never during the fourteen month period was heating required during the class day. That is, the internal load more than met the heating requirement.

Such was not the case for the test classroom with the furnace only. This room had 100% fresh air circulated and hence, the operation of the furnace was governed much more closely by outside conditions. This room required heating much sooner as the outside temperature dropped than did the other two test rooms. In this situation the greater fresh air intake worked to a disadvantage; however, once there was internal heat generation in the room, the larger quantity of fresh air delivery made it possible to maintain room design conditions for a period without cooling equipment. In the absorption and heat pump rooms, when the outside ambient reached to within 10°F. of the room temperature, the room temperature started to rise at a rate approximately equal to 30% of the rate of the outside temperature change. This figure varied slightly depending on the relative time between the occurence of the change in the outside temperature and the time of the load in the classroom. In the rooms provided with cooling it would have been advantageous to have had more fresh air not only when the outside ambient was lower than the room design temperature, but on several occasions during the summer and fall. Occasionally during these periods, the energy level of the return air entering the cooling units as measured by the wet bulb temperature was higher than the energy level of the outside air, even though the outside air had a higher dry bulb temperature. Recirculating 80% of the return air thus required more cooling from the units than if a greater quantity of fresh air had been used. The favorable effect of an automatic fresh air mixing control can be seen in light of these conditions.

Very little can be said concerning the relationship between outside temperatures and cooling. One of the colder days of the year during which classes were in session was January 5, 1960; the day's high being 70°F. The cooling cycle of both units went on at approximately 9:00 AM when the outside temperature was 53°F. With these units bringing in only 20% fresh air, the energy generated in the room was of sufficient magnitude to increase all the air to 73°F. at which time the units came on the cooling cycle. On the other hand, the May 6, 1959 graphs show the cooling cycle coming on with an outside temperature of 65°F., this occurring between 9:00 am and 10:00 am. The October 14, 1959 graphs show the cooling cycle coming on again about 9:30 AM but at an outside temperature of 75°F. From the graphs it is seen that the outside temperature for this day rose very rapidly. Thus, as long as these rooms had 20% fresh air intake and were maintained at a temperature within limits of the thermostat setting, cooling was required approximately one and one-half hours following the beginning of class, whether the outside temperature was 55°F., 65°F., or 75°F. The hours of cooling required were, of course, a function of the outside temperature.

The favorable thermal effect of the Airfloor is seen in the set of graphs for October 14, 1959, during which day the outside temperature reached 96°F. The air being discharged from the Hayes blower reached 100°F.; yet even with the heat generation in the room the room temperature did not exceed 87°F. At this same time the temperature in the absorption room reached a 77°F. peak and the heat pump room a peak of 79°F. A comprehensive analysis of the Airfloor system is presented on pages 59 to 60.

The minimum daily high temperature of the test was 57°F. and occurred on December 31, 1959, when the nighttime low was 48°F. There were no classes from the 18th of December to the 4th of January, hence this day would have required the greatest amount of heating to maintain design temperatures. The maximum floor temperature on this day in the Arkla and Typhoon rooms was 74°F. In the classroom with the furnace only, the maximum floor temperature reached was 83°F. This was due to the 120°F. discharge from the furnace in contrast to 99°F. maximum discharge temperature from the absorption unit and 88°F. from the heat pump unit. The lowest and highest floor temperatures occurred at the supply trench end of the room. On May 6, 1959 following seven hours of cooling, the floor temperature dropped to 65°F. in the absorption room and 68°F. in the Typhoon room. Generally in these two rooms the temperatures over the entire floor were in the 69°F. – 74°F. range. In the room without cooling, the floor temperature reached 89°F. on October 14, 1959.

The supply or register air delivered into the room did not vary much in temperature whether the units were on the heating or cooling cycles. In the heat pump room the supply or register air was always at 72°F. plus or minus 3°F., while in the absorption room the supply air was 71°F. plus or minus 3°F. For October 14, 1959, on which day the outside ambient varied 40°F. (50°F. – 96°F.), the supply air in both rooms provided with cooling varied 3°F. In the non-cooled room the variation was 14°F.

The rooms during occupancy were held in the comfort region throughout the test. Generally, the humidity was in the 30%–60% range and the dry bulb temperatures in the 69°F.–78°F. range. There were a few days in which the outside temperature reach 96°F. and once during this period, the room temperature reached 80°F. in the cooled room. Excessive room temperatures occurred when the outside temperature rose rapidly to values in the 95°F. – 100°F. region. This condition was caused by not having any anticipator controls in the system coupled with the fact that the units did not go on the cooling cycle until room temperatures were 74°F.–76°F. and later 72°F.–74°F., following the resetting of the thermostats.

TABLE D

MONTHLY MEAN TEMPERATURES

MONTH	OUTSIDE TEMPERATURES				TYPHOON ROOM TEMPERATURES		ARKLA ROOM TEMPERATURES		HAYES ROOM TEMPERATURE	
	MEAN HIGH	DEVIATION	MEAN LOW	DEVIATION	HIGH	LOW	HIGH	LOW	HIGH	LOW
April (9-30) 1959	78	12, -11	60	3, -2	76(2, -3)	69(0, -1)	76(1, -3)	69(1, -1)	78(4, -2)	69(2, -2)
May	73	9, -3	56	7, -6	76(1, -1)	69(1, -1)	75(1, -1)	69(1, -1)	78(2, -2)	69(2, -4)
June	84	5, -6	65	4, -4	-	-	-	-	-	-
July	88	15, -6	68	5, -4	-	-	-	-	-	-
August	87	14, -9	67	7, -8	76(0, -1)	71(2, -2)	76(1, -2)	70(1, -1)	-	-
September	83	17, -10	65	7, -4	76(3, -1)	71(1, -2)	75(1, -2)	70(2, -1)	84(8, -3)	75(5, -3)
October	83	12, -13	61	6, -5	77(2, -3)	69(3, -2)	76(1, -2)	69(2, -0)	82(5, -4)	72(2, -2)
November	83	11, -13	55	6, -4	77(2, -4)	69(1, -3)	76(3, -2)	70(1, -2)	80(5, -3)	70(2, -3)
December	71	12, -14	52	8, -11	74(3, -2)	69(1, -1)	75(2, -4)	70(1, -1)	77(5, -3)	69(1, -2)
January, 1960	69	19, -9	48	10, -9	75(3, -2)	69(1, -1)	75(2, -3)	69(1, -1)	76(4, -3)	68(3, -3)
February	68	13, -8	50	5, -5	75(2, -1)	68(1, -0)	76(2, -1)	68(2, -2)	76(3, -3)	69(1, -4)
March	75	15, -14	55	3, -6	77(2, -2)	69(1, -11)	76(2, -1)	68(1, -2)	78(4, -3)	69(2, -2)
April	78	14, -11	56	5, -3	77(3, -4)	69(1, -1)	77(7, -4)	69(2, -1)	-	-
May	80	12, -9	58	4, -4	77(4, -2)	69(1, -1)	77(3, -2)	69(2, -2)	81(7, -2)	71(3, -1)
June (1-17) 1960	80	4, -10	63	1, -3	76(1, -3)	69(1, -0)	75(2, -2)	69(1, -1)	79(6, -3)	70(2, -1)

All the mean temperatures shown do not include the temperatures recorded during the period from 4PM Friday to 4AM Monday during which time the Heat Pump and Absorption units were not in operation.

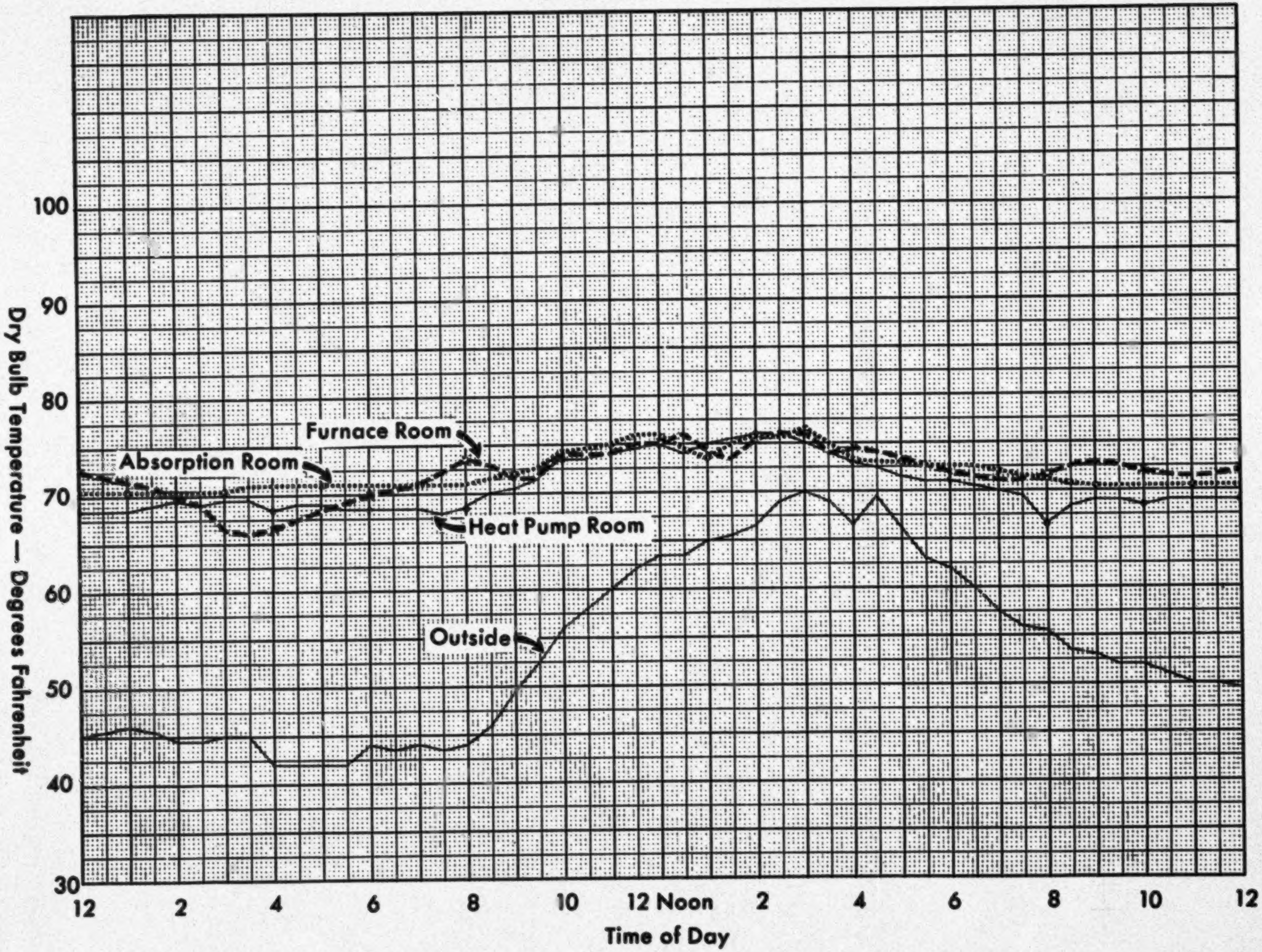
TEMPERATURE CHART INDEX

DATE	OUTSIDE TEMPERATURE	PAGES
January 5, 1960	41° - 70°F.	37 - 41
May 6, 1959	54° - 82°F.	43 - 48
October 14, 1959	56° - 96°F.	49 - 54

January 5, 1960

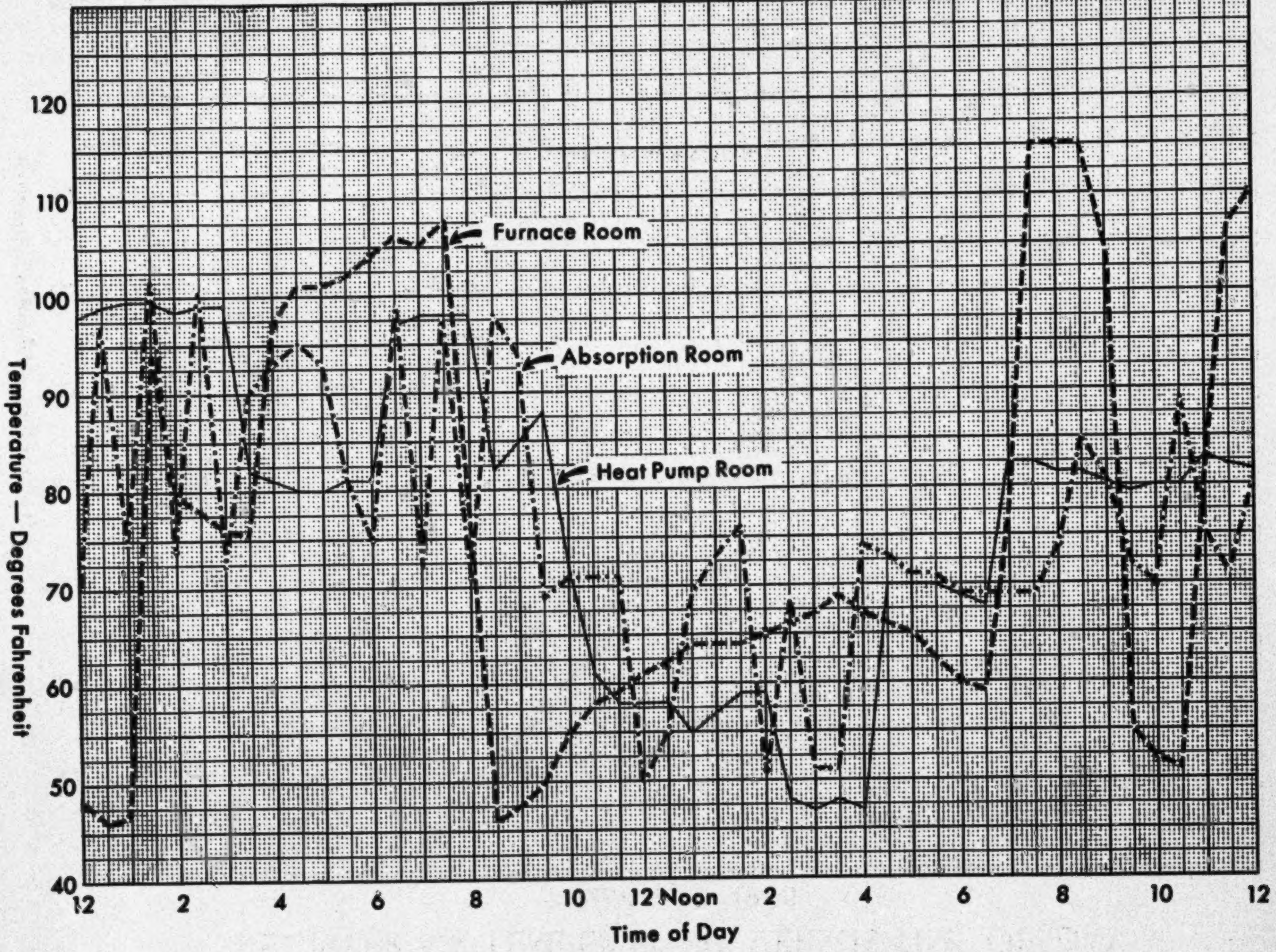
DRY BULB TEMPERATURE VERSUS TIME OF DAY

January 5, 1960



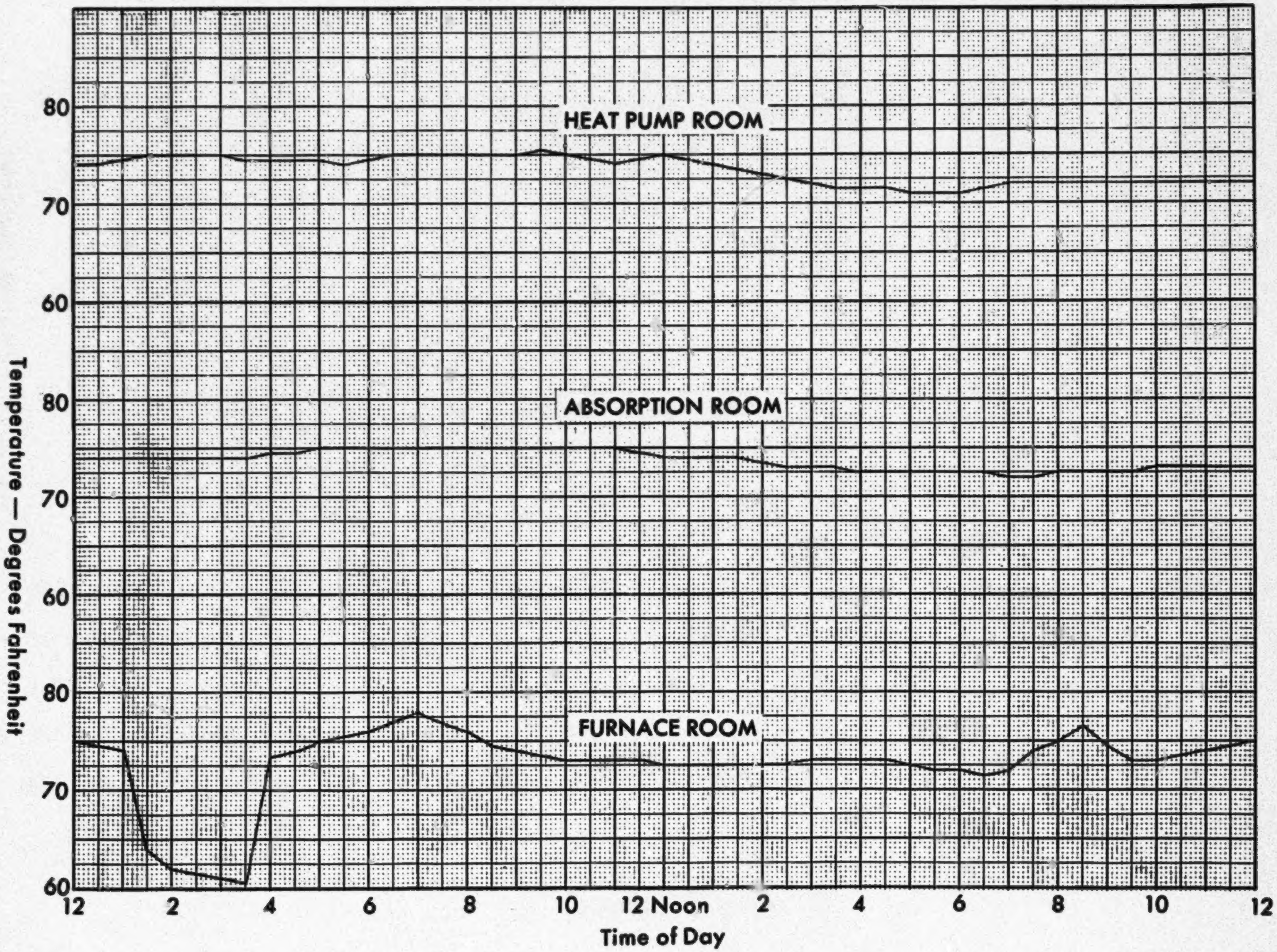
DISCHARGE AIR TEMPERATURE VERSUS TIME OF DAY

January 5, 1960



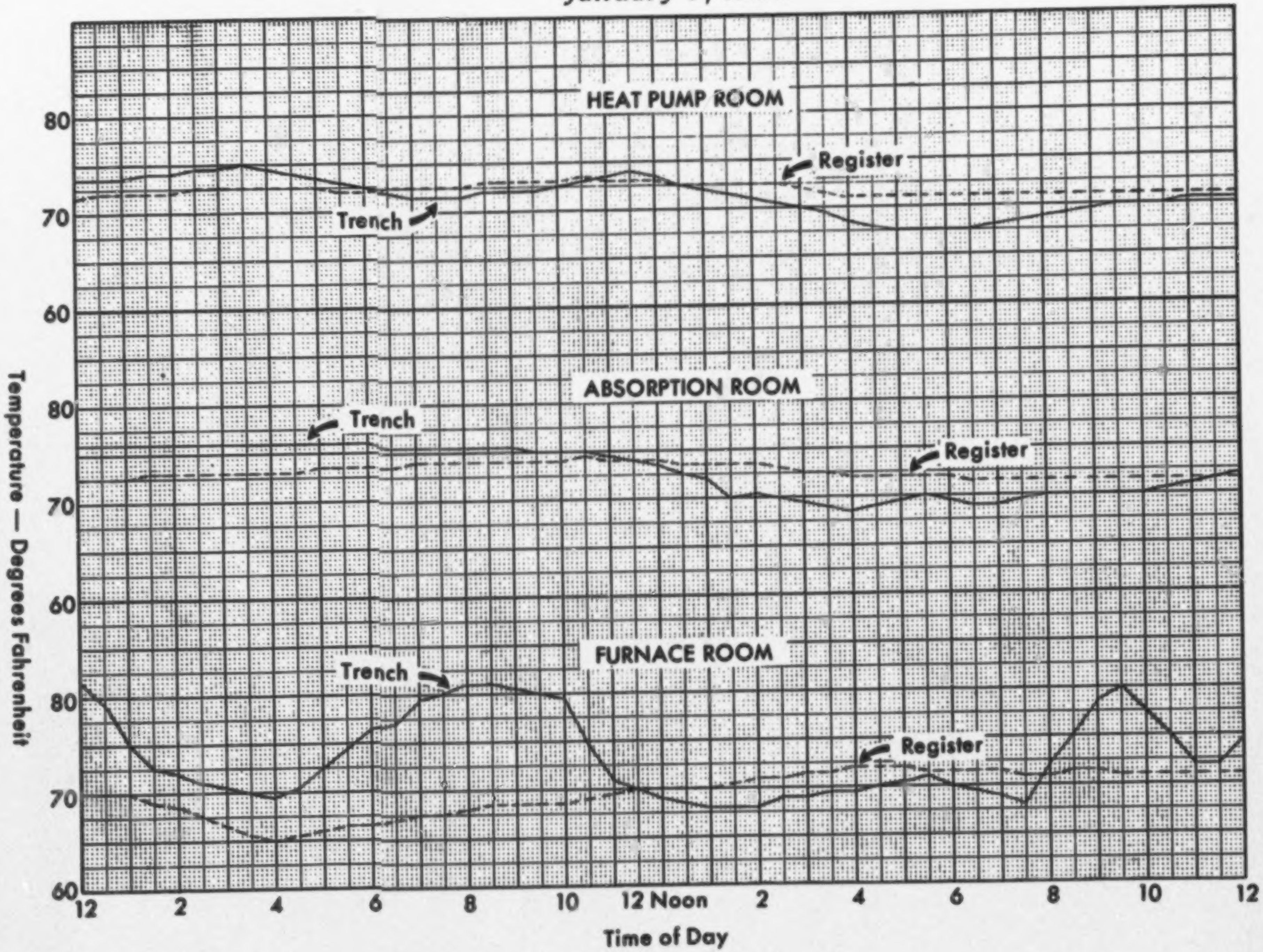
REGISTER AIR TEMPERATURE VERSUS TIME OF DAY

January 5, 1960



FLOOR TEMPERATURE AT REGISTER AND TRENCH VERSUS TIME OF DAY

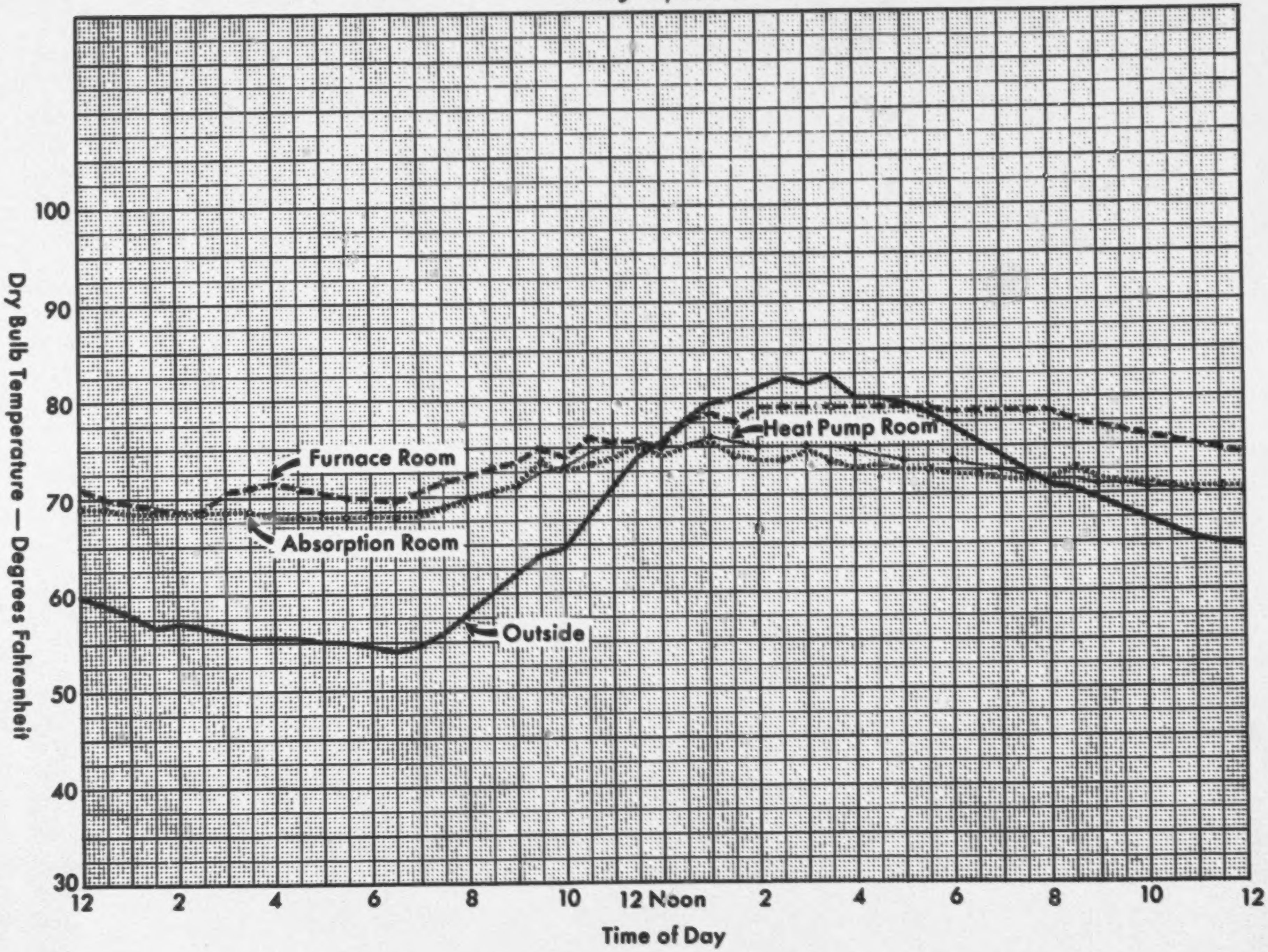
January 5, 1960



May 6, 1959

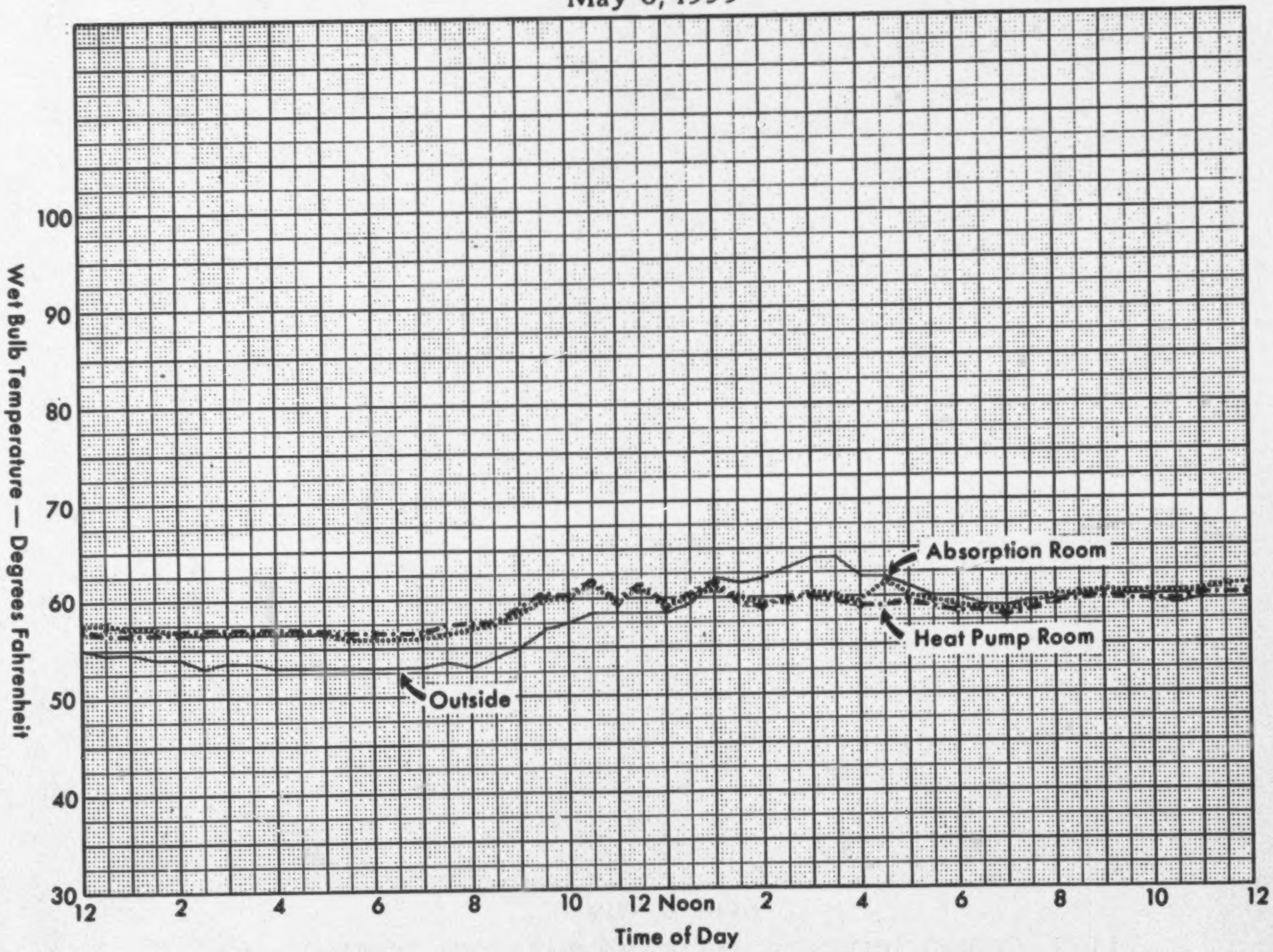
DRY BULB TEMPERATURE VERSUS TIME OF DAY

May 6, 1959



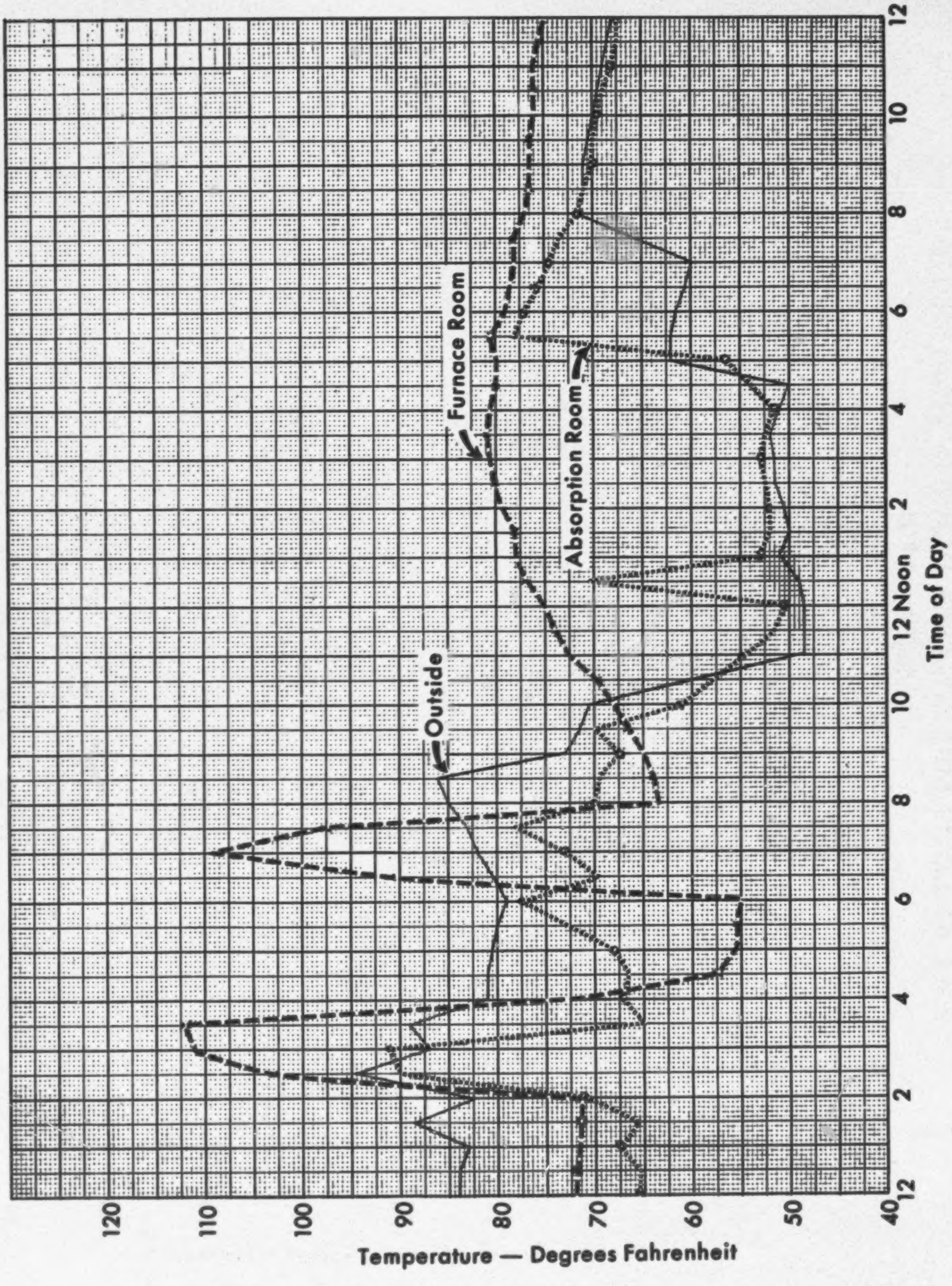
WET BULB TEMPERATURE VERSUS TIME OF DAY

May 6, 1959



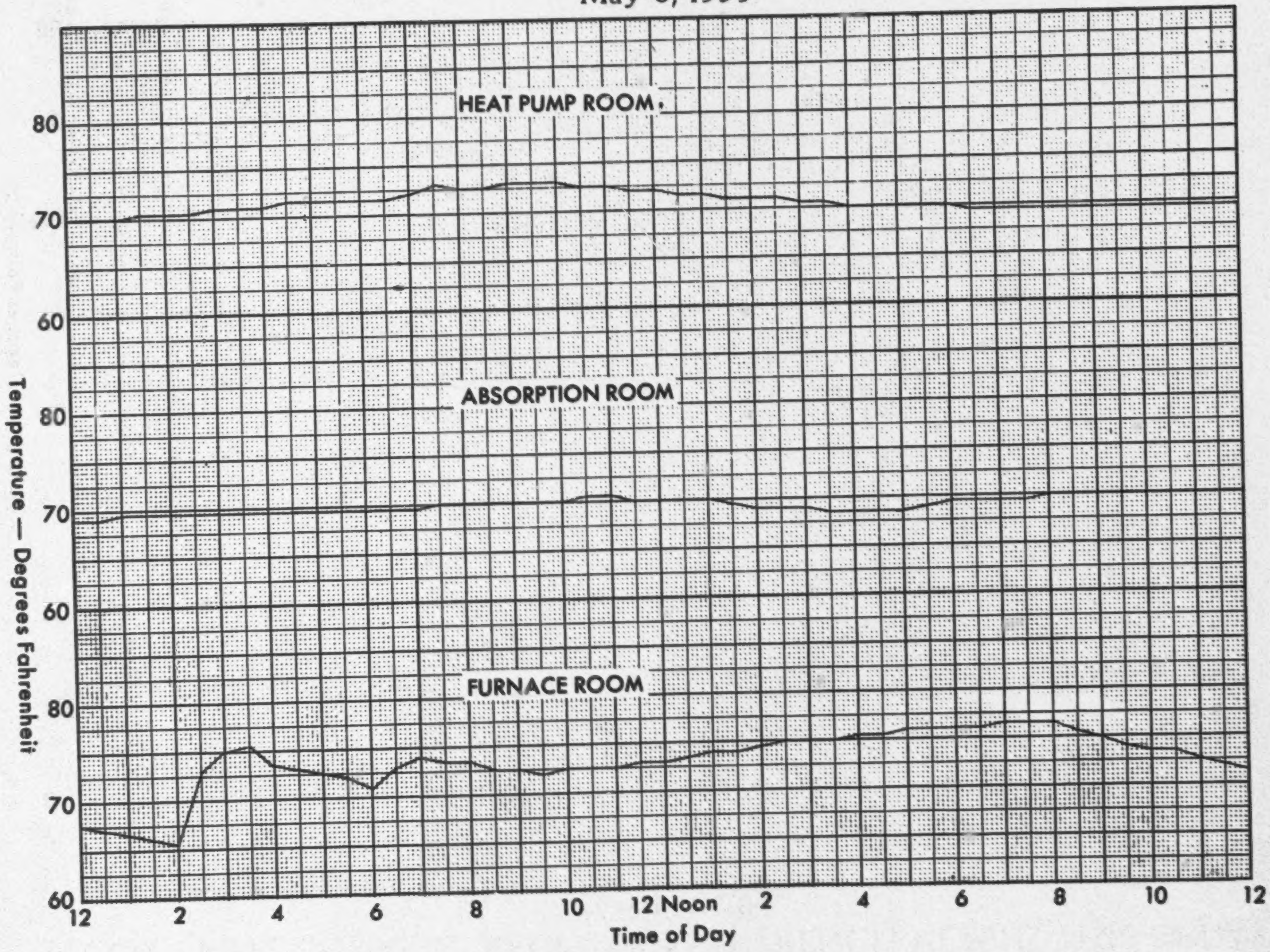
DISCHARGE AIR TEMPERATURE VERSUS TIME OF DAY

May 6, 1959



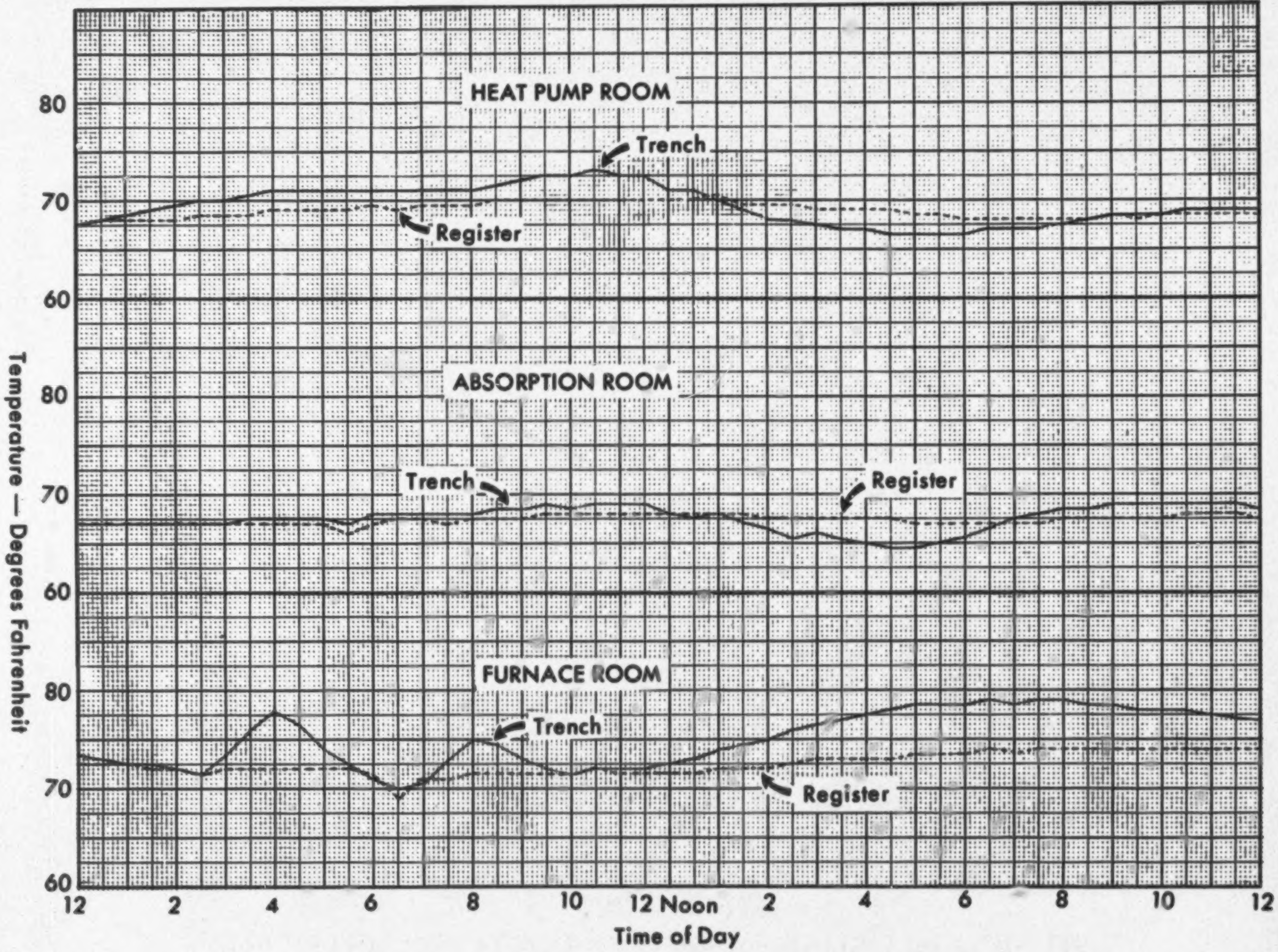
REGISTER AIR TEMPERATURE VERSUS TIME OF DAY

May 6, 1959



FLOOR TEMPERATURE AT REGISTER AND TRENCH VERSUS TIME OF DAY

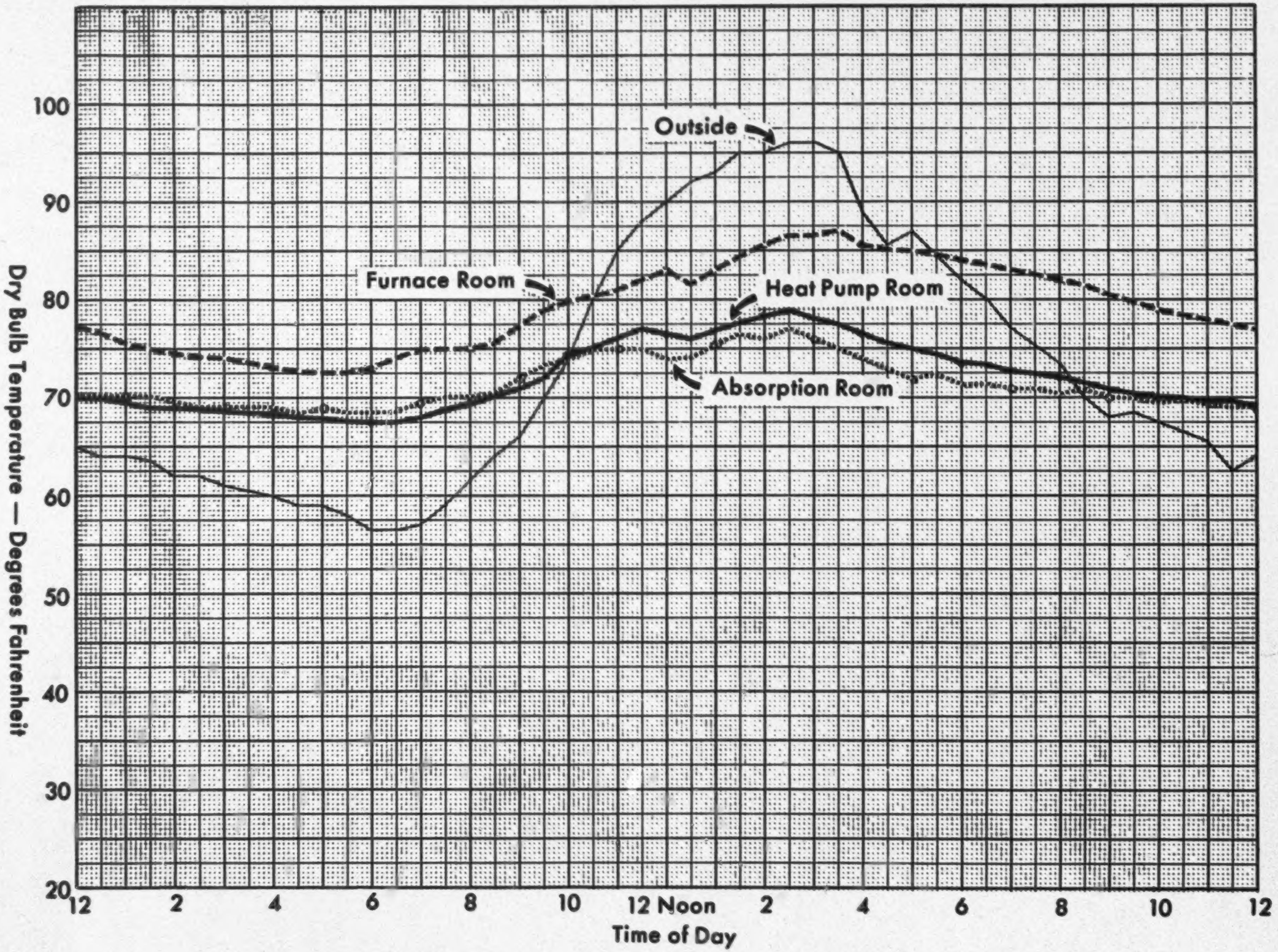
May 6, 1959



October 14, 1959

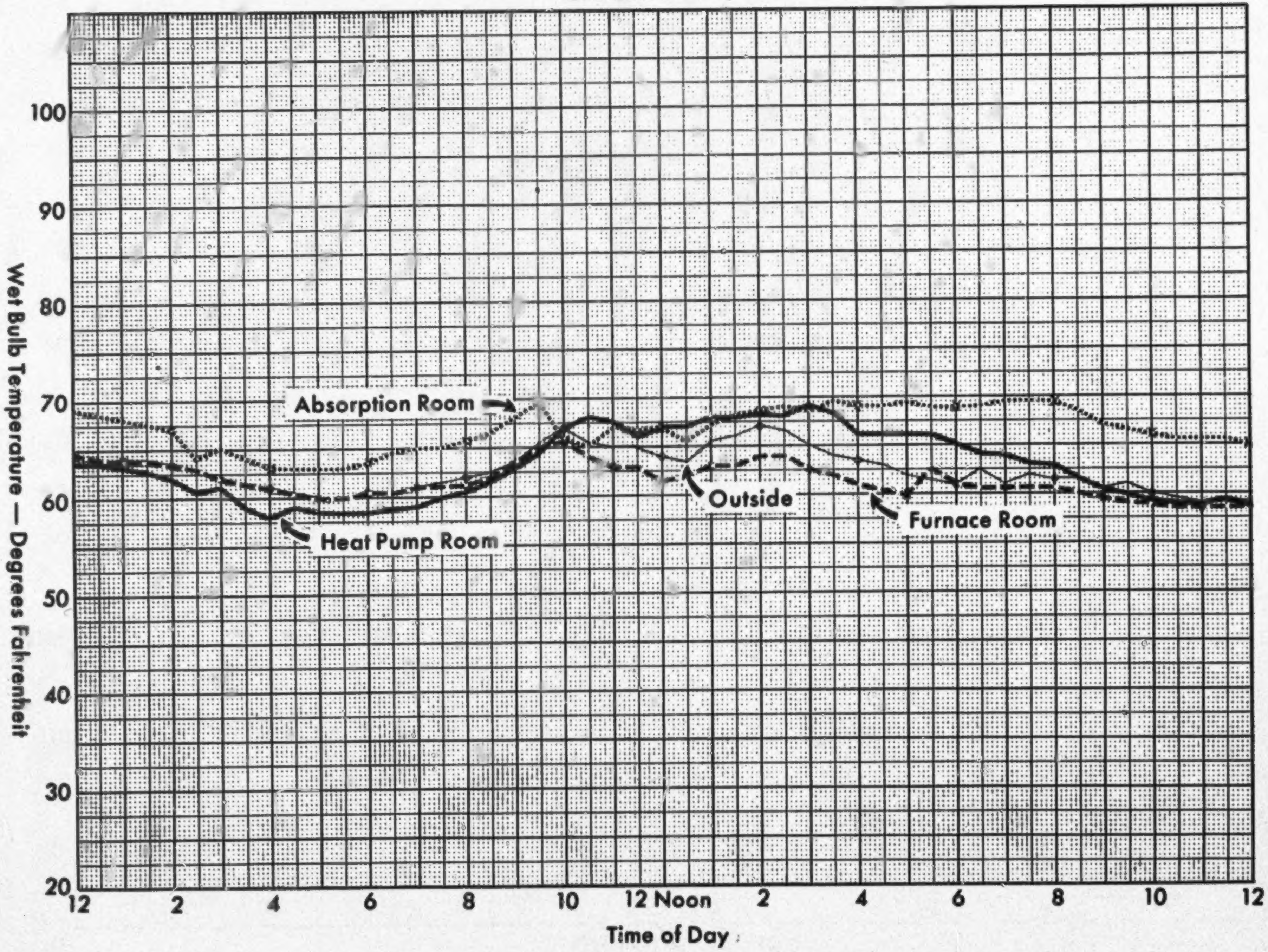
DRY BULB TEMPERATURE VERSUS TIME OF DAY

October 14, 1959



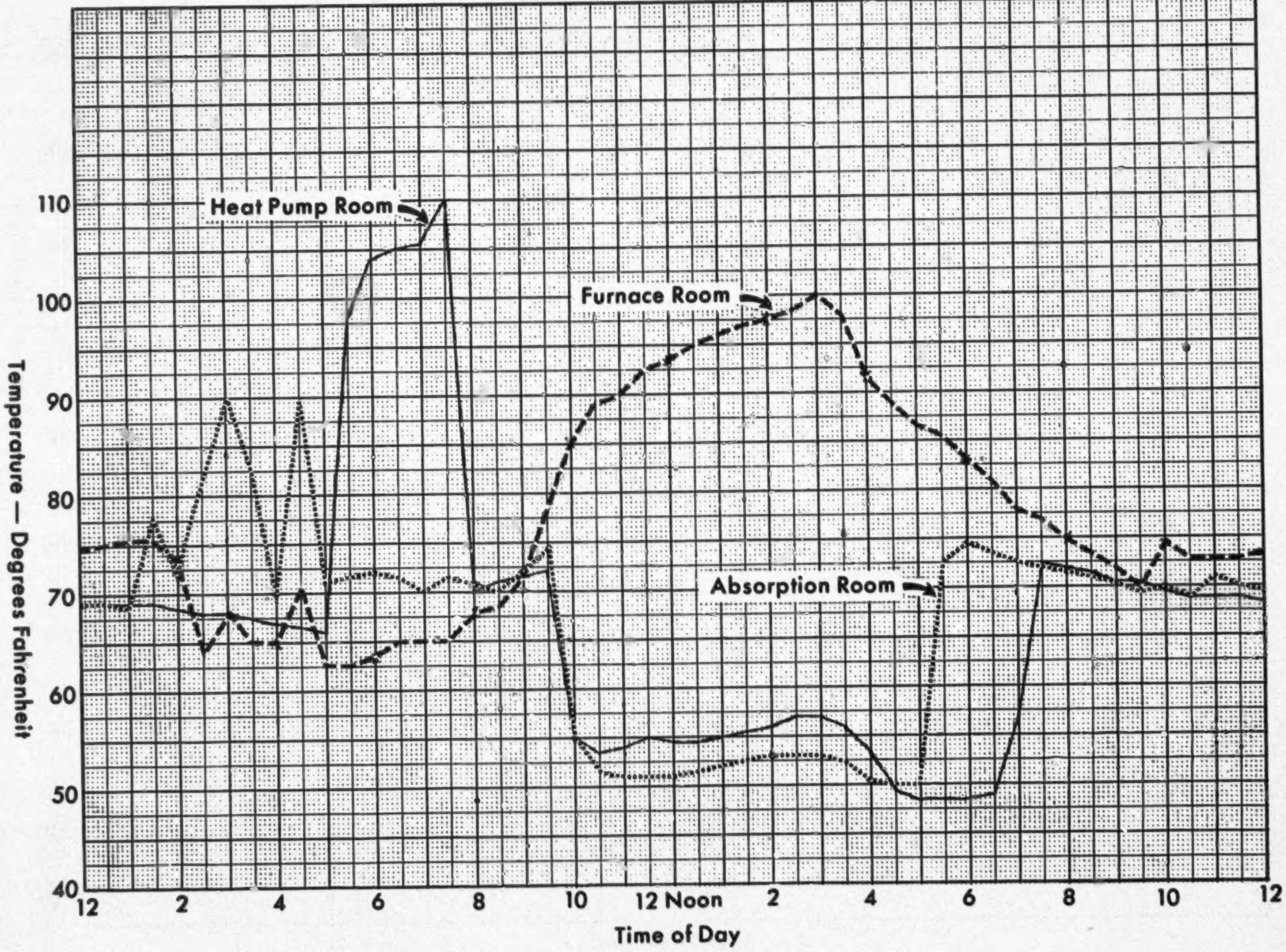
WET BULB TEMPERATURE VERSUS TIME OF DAY

October 14, 1959



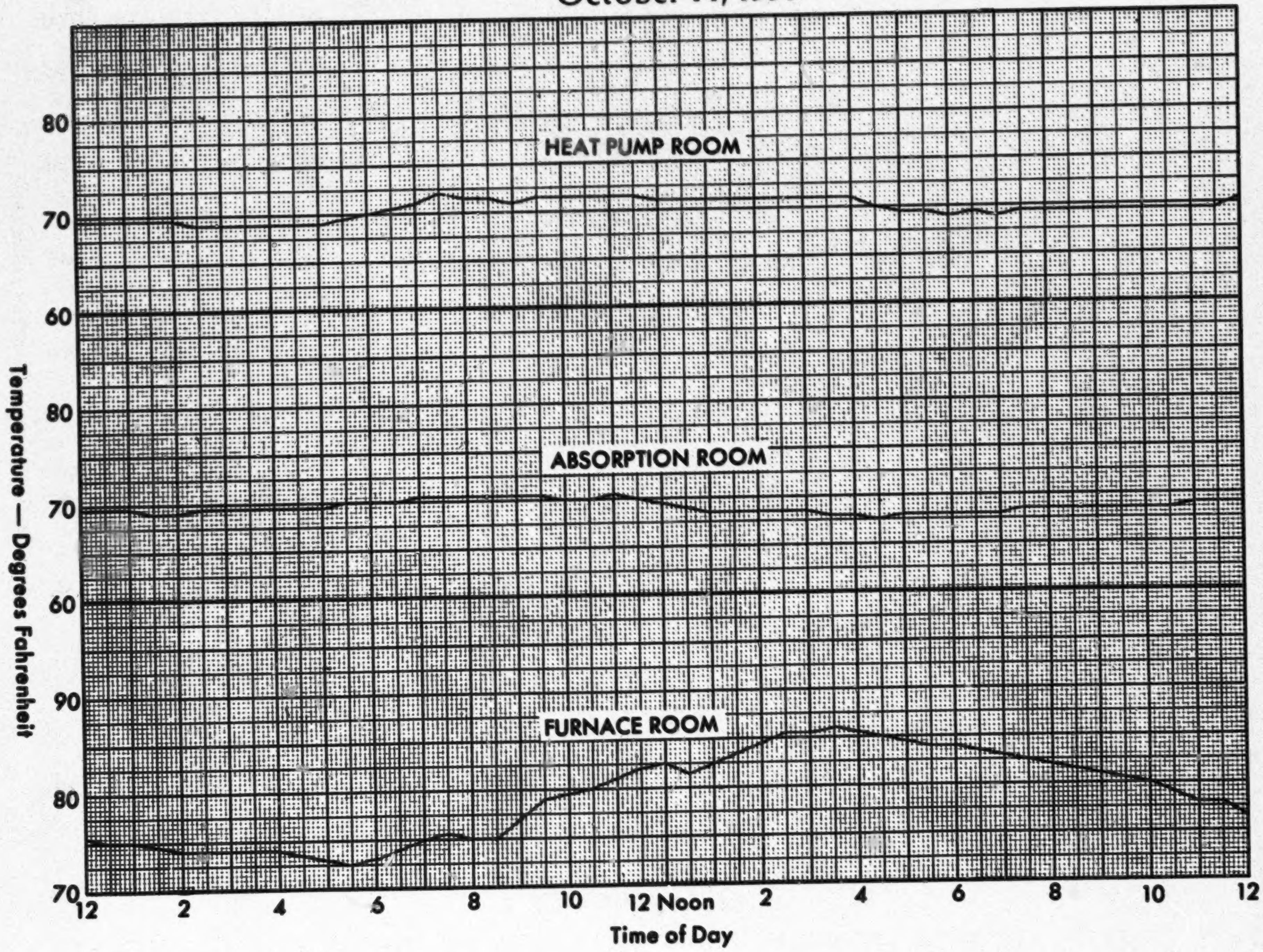
DISCHARGE AIR TEMPERATURE VERSUS TIME OF DAY

October 14, 1959



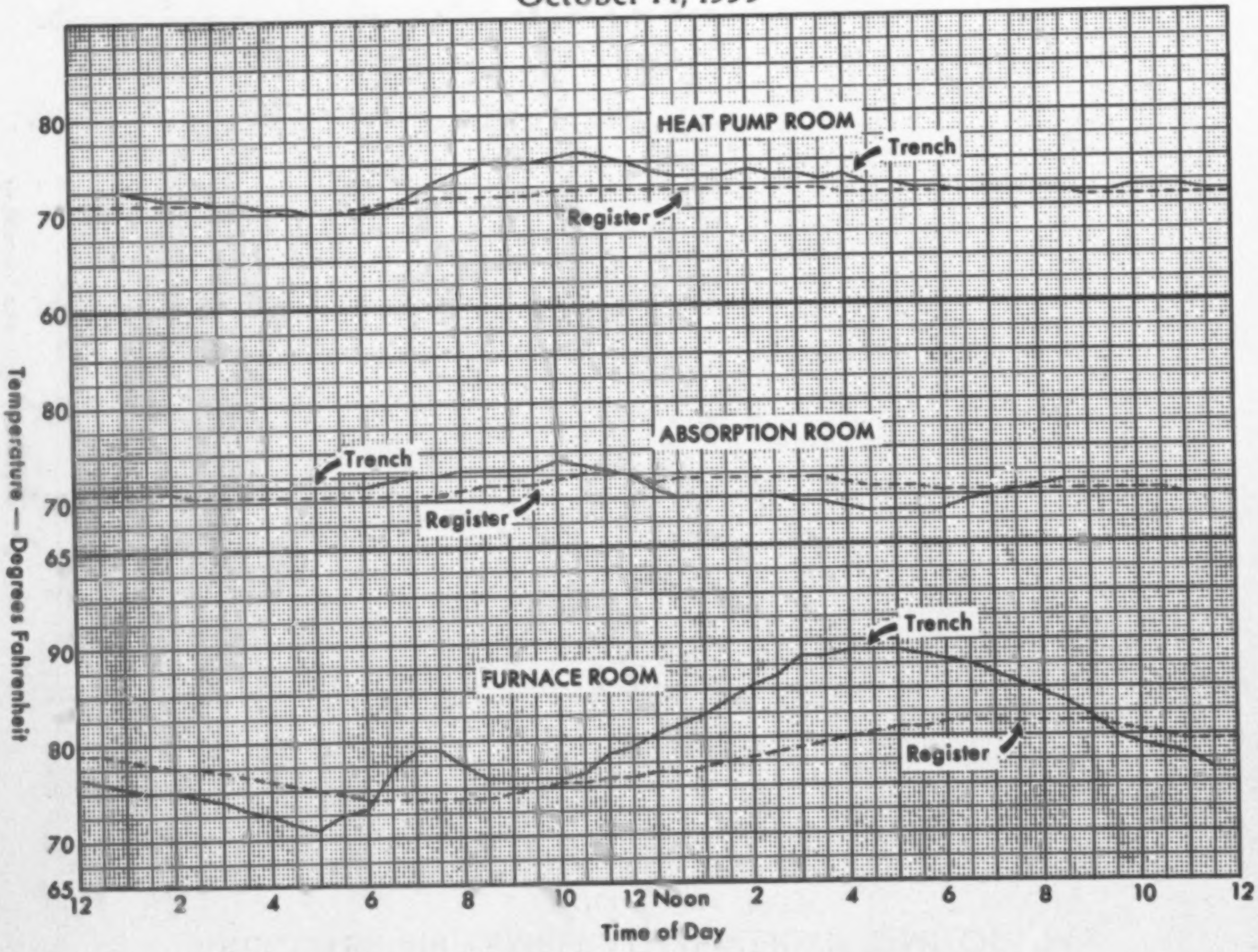
REGISTER AIR TEMPERATURE VERSUS TIME OF DAY

October 14, 1959



FLOOR TEMPERATURE AT REGISTER AND TRENCH VERSUS TIME OF DAY

October 14, 1959



Load Analysis

Load Analysis

The two test rooms provided with cooling were subject to very similar exterior conditions, each having one wall with an eastern exposure and one with western exposure. The other two walls of each classroom were maintained between 68°F. and 75°F., except during weekends when the units were not in operation. From the plot plans on pages 17 and 18 it is seen that the third test room, which did not have cooling was oriented the same as the first two test rooms; however, its adjoining rooms on the north and south were not provided with cooling and therefore the test room, like the first two test rooms, had no heat transfer to adjoining rooms. The only physical difference between the cooled and non-cooled rooms occurred in the roof. The cooled rooms, unlike the non-cooled room, were provided with four inches of blown-in rock wool roof insulation. The effect of this was to increase the thermal resistance approximately 75%. This also increased the time required for an outside change in temperature to become detectable on the interior. The thermal lag in the roof amounts to about two and one half hours; that is, the contribution of the sun's energy to the total cooling load at any time is that energy received from the sun two and one half hours earlier.

The lighting, students, and teacher provided the only heat sources in the room. The lighting provided 1.62 kilowatts of heating in each of the rooms (the lighting level was less than 1.8 watts per square foot). From the start of the test in Spring, 1959 until the close of the Spring term, the lights were left on throughout the day except for the noon hour; however, beginning in September, 1959 the lights were off during all the recesses. Following is a typical schedule of the classes occupying the test rooms:

Teacher arrival	**8:30 - 9:00 AM**
Class	**9:00 - 9:50**
Recess (Outside)	**9:50 - 10:00**
Class	**10:00 - 10:50**
Recess (Outside)	**10:50 - 11:00**
Class	**11:00 - 11:30**
Lunch (Outside)	**11:30 - 12:10 PM**
Class	**12:10 - 1:00**
Break (Outside)	**1:00 - 1:05**
Class	**1:05 - 1:30**
Physical Education (Outside)	**1:30 - 1:50**
Class	**1:50 - 2:05**
Teacher departure	**2:30 - 5:00**

The children occupied the rooms 3.67 hours per day on the average. Occasionally the two classes met together for half an hour during the day and on occasion the physical education period (exercises, games, etc.) was held in the rooms.

The average number of children in the rooms ranged from twenty in May, 1959 to forty in September, 1959. The average for the year in each of the rooms was approximately thirty children. The variation in child enrollment is shown on a monthly basis on page 61. First graders, ranging in age from six to seven years of age, occupied both the cooled test rooms. In the non-cooled test room were second and third graders in the seven to eight year age bracket. For the internal heat generation calculations, the children were assumed to liberate 350 Btu per hour and the teacher 470 Btu per hour. The internal heat generation therefore totaled approximately 16,000 Btu per hour.

In the latter part of February, 1960 additional wet bulb apparatus was installed at the supply register and in the return air duct. This was done to determine the cooling effect of the air as it passed through the room; also, knowing the discharge condition from the cooling coils made it possible to determine the temporary and "flywheel" effects of the Airfloor system as well as the amount of cooling provided by the units. The system was pre-set to utilize 20% fresh air under all conditions.

The air flow rates of the units were measured at 70°F. dry bulb and 58°F. wet bulb. The Arkla unit delivered 1460 c.f.m. and the Typhoon unit delivered 1700 c.f.m.

The table on page 62 gives the gain in energy in the air between discharge from the cooling units and entering the return duct. Also presented in this table is the energy pickup of the air across the Airfloor system and the cooling provided by the units. This data is tabulated as a function of the dry bulb and wet bulb temperatures. Also shown in the table is the lowest temperature occurring in the morning which has a significant effect. The loads are the average hourly loads for the period of 1:00 – 3:00 PM.

The table F on page 62 shows that the energy gain of the air reached a minimum when the outside temperature was at 85°F. This was true in both rooms. The energy gain of the air when the temperature was less than 85°F. was largely due to a longer period of operation of the units on the heating cycle before going onto the cooling cycle. The heat gain was also affected by the duration of time between the heating and cooling cycles and by the length of time the units were on cooling before the load test period began. The reason for the importance of these quantities is the energy storage capacity of the concrete slab of the Airfloor system. For example, if the equipment was on heating from midnight to 9:30 AM, followed by a period of two hours of cooling before the load test period began at 1:00 PM, the measured energy gain of the air would be different than if there was two hours of heating in the early morning followed by air circulation and then four hours of cooling before the test began, even though in the latter case the outside temperature was higher when the test took place. The air gains more energy from the pre-heated slab in the first case than in the second case and this ends up being greater than the excess gain in energy due to the higher outside temperature in the second case over the first. In the discussion following, the effects of the slab are analyzed. When the outside ambient temperature becomes 90°F., the load gain from the outside begins to take the dominant role. The thermal lag of the building itself prevents the load from increasing more rapidly with increasing outside temperature. This is evident in looking at the energy gain of the air just as it passes from the supply register to the return register.

The natural conditions of the atmosphere and wind velocity contribute significantly to the heat transfer, as do the number of door openings into the classrooms. The former effects were not noted but the latter was tabulated for a week's period and found on the average to be about thirty door openings per day. As many as forty-five and as few as twenty-one openings per day were recorded during the week.

In Table F on page 62 the cooling provided by the Arkla Servel Absorption Unit and the Typhoon Heat Pump Unit is also shown plotted for nine days in May. In computing these loads as well as the other loads in this table, the following procedure was used. The dry bulb and wet bulb temperatures were averaged for the two-hour period from 1:00 PM to 3:00 PM at the supply register, return register, and outside. An average of the dry bulb temperature at the discharge of each unit was also obtained. From the dry bulb and wet bulb data the energy level of the air was determined. Taking 80% return air and 20% fresh air passing through a sensible cooling process, the energy level of the discharge air from the units was found. This procedure is illustrated by looking at the Arkla room on May 12, 1960 as an example. Following are average temperatures between 1 PM and 3 PM taken at several locations and the corresponding average energy levels (h, Btu per pound of dry air) as taken from the Carrier psychrometric chart.

OUTSIDE AIR			ARKLA SUPPLY AIR			ARKLA RETURN AIR			ARKLA DISCHARGE AIR
d.b.	w.b.	h_o	d.b.	w.b.	h_s	d.b.	w.b.	h_r	d.b.
87.0°	64.0°	29.2	70.0°	57.3°	24.7	77.5°	61.1°	27.2	53.9°

The volumetric flow of 1,460 cfm provided a mass flow rate, m, of 6,500 lbm/hour. Assume the density of the outside and return air to be the same. With 20% fresh air the energy level of air entering the unit, h_m, was $(.2 \times h_o + .8 \times h_r) = 27.6$ Btu/lbm of d.a. and the entering dry bulb temperature was $(.2 \times \text{d.b.t}_o + .8 \times \text{d.b.t}_r) = 79.5$°F. Passing through a sensible cooling process to a discharge dry bulb temperature of 53.9°F. gives a discharge wet bulb temperature of 53.3°F. and an energy level, h_d, of 21.2 Btu/lbm of d.a. Continuing with this example to compute the load it is

seen that the energy removed by the Arkla unit was:
$m(hm-hd) = 41{,}700$ Btu/hour
The energy gain of the air across the floor was
$m(h_s-hd) = 22{,}700$ Btu/hour
the energy gain across the room was
$m(h_r-h_s) = 16{,}300$ Btu/hour
giving a total gain in energy of the air between entering and leaving the room of 39,000 Btu/hour.

Weekly the temperature apparatus was calibrated but was not reset to give correct readings; instead, the corrections were applied to the recorded data. The calibrations were made on the wet bulb equipment to ±0.5°F. In computing the change in energy level of the air between any two locations it was therefore possible to reduce the error in wet bulb data to 0.5°F. This error would result in an error in the energy level of the air of approximately 0.4 Btu per pound of dry air. In the Arkla installation with 6,500 pounds of dry air per hour being circulated, this would result in an error of nearly 2,600 Btu per hour. The average cooling provided by the Arkla unit was 41,000 Btu per hour in contrast to its rated capacity of 42,000 Btu per hour. The Typhoon unit provided an average cooling rate of 40,000 Btu per hour during this May period compared to its rated capacity of 35,000 Btu per hour. The rated capacity of both units is based upon inlet air at 80°F. dry bulb and 67°F. wet bulb; and in addition, the Arkla unit requires inlet water at 75°F. and 444 gph, whereas the Typhoon unit requires 95°F. to the condenser for rated capacity.

Previously it was noted that the effects of the Airfloor were noticeable. In looking at the temperature charts on pages 37 to 54 and comparing the discharge temperature at any time to the supply air temperature at the corresponding time, the tempering effect of the slab is prominent. It affects the amount of cooling and heating required as pointed out above. The average daily high temperature during the fourteen months of the experiment was 79°F. In order to give quantitative values to its effect the day of October 14, 1960 was analyzed. (A complete set of temperature graphs for this day are on pages 49 to 54). The Typhoon Heat Pump installation was chosen due to the fact that there was no cycling of the unit when on the heating cycle. October 14 was chosen because at 12:00 AM the discharge air and supply air were at the same temperature, signifying equilibrium of the slab at that temperature. At 5:15 AM the heating cycle came on with second stage operation. It remained on until 7:40 and pure air circulation followed until 10:00 AM, after which second stage cooling came on and remained on until 6:00 PM. Air circulation followed until midnight, bringing the slab to within 1°F. of the temperature it had twenty-four hours earlier.

A transient analysis involving the sensible heat change of the concrete slab, revealed that the top portion of the slab over the Airfloor ducting reached to within 2°F. of its equilibrium temperature at the trench and after the 2.3 hours of second stage heating. The average over-slab temperature was 90°F. assuming 107°F. discharge from the unit and allowing 3°F. drop in the ducts and supply trench between the unit and the slab. The average temperature of the over-slab at the air register, the point where air leaves the slab, was 72°F. Assuming the temperature rise varied linearly across the floor from supply trench to supply register, a final average temperature of the entire over-slab of 80°F. resulted, this following 2.3 hours of heating cycle operation discharging air at 107°F. The mean thickness of the over-slab was assumed to be 2.5 inches. The sub-slab analysis resulted in virtually the same conditions. Before the heating cycle came on, the average entire slab temperature was 68°F. Thus, the slab had an average rise in temperature of 12°F. during the 2.3 hours of heating. The concrete in each room, covering an area of 900 square feet and having a total mean thickness of 4.5 inches (sub-slab was a uniform thickness of two inches), had a heat capacity of approximately 11,000 Btu per degree Fahrenheit temperature change. Thus, during heating the slab stored about 132,000 Btu. An additional amount of energy was stored in the ground adjacent to the sub-slab. At the trench end the analysis showed the ground to a depth of nearly ten inches was affected by the heating. The average change in temperature of the ten-inch depth at the supply trench was 2°F. The effect on the ground at the supply register end was negligible, thus the energy stored in the ground amounted to 14,000 Btu. The total stored energy during the heating amounted to approximately 146,000 Btu.

During the heating period the 7,540 pounds per hour of dry air supplied to the floor at 104°F. dropped to an average temperature of 70°F. at the supply register. The air thus gave up 63,000 Btu per hour or 143,000 Btu for the 2.3 hour period. At the same time the floor was transferring energy to the room by radiation and convection at an estimated rate of 4,500 Btu per hour or 10,400 Btu for the period. This amounts to a net heat addition to the slab of approximately 133,000 Btu as compared to 146,000 Btu obtained by the transient analysis.

Following the heating cycle there was a period of two hours and ten minutes of solely air circulation during which the slab transferred about 12,000 Btu to the room, resulting in a 1°F. average drop of temperature to 79°F. The cooling cycle of the unit came on at 10:00 AM and remained on for eight hours, operating on second stage cooling and delivering air at an average temperature of 53°F. for the period of cooling. The average slab temperature following the cooling was 65°F. which means the slab had a decrease of 154,000 Btu, or a total decrease in stored energy of 179,000 Btu. The air passing through the floor during this time picked up 235,000 Btu from the floor, but at the same time the floor, by radiation and convection, picked up 83,000 Btu from the room, leaving a net change in the energy transferred from the slab of 172,000 Btu compared to the 179,000 Btu obtained by the analysis.

The graph on page 63 shows (1) the energy transferred to or from the floor by the air passing through the Airfloor, (2) the energy transferred to or from the floor by convection and radiation and, (3) the net energy transferred to the floor against the time of day for October 14, 1959. It is noteworthy that for the entire day the negative area on the graph is greater than the positive area by 14,000 Btu, signifying that there is a decrease in the energy level of the slab during the twenty-four hour period of 14,000 Btu or a decrease of temperature of approximately 1°F. in the average slab temperature. This change is noted on the graph on page 54 which shows the floor temperature at the register and trench for this day.

The preceding example shows the effect of the Airfloor when used with a heating-cooling cycle. The example taken does not represent the average day, but represents a typical day in which both the heating and cooling cycles would be necessary. When the early morning temperature did not pass below the point where heating was required, the slab, cooled by the lower temperature classroom and outside air, was a potential "sink" for energy of 11,000 Btu per degree cooled.

In the above example, during the heating cycle there was approximately 5,000 Btu of energy being transferred to the room through the floor while the supply air to the room was 71°F. This is with 107°F. air being discharged from the heat pump. The tempering effect of the slab is even more prominent in the case of the Arkla or Hayes Furnace units, for these units discharge air up to 120°F.

A similar situation occurs on the cooling cycle. At 2:00 PM energy was being removed from the room through the floor at a rate of 16,000 Btu per hour. The 53°F. air being discharged from the unit was put in the room at a temperature of 71°F. (This was an average temperature. The maximum supply register temperature was 71.5°F. and the minimum was 69°F., occurring after eight hours of cooling.)

During the heating cycle, 50% of the sensible heat added to the room came by way of the floor while the remaining 50% was given up by the air as it passed from the supply register to the return register. During cooling, 53% of the sensible heat was taken out through the floor with the increase in sensible energy of the air passing through the room accounting for the remaining 47%.

TABLE E

INTERNAL HEAT GENERATION

MONTH	NUMBER OF SCHOOL DAYS	AVERAGE NUMBER OF STUDENTS PER SCHOOL DAY			AVERAGE HOURS PER DAY IN CLASSROOM	AVERAGE HOURS LIGHTS USED PER SCHOOL DAY			AVERAGE HOURS TEACHER IN ROOM PER SCHOOL DAY			AVERAGE INTERNAL HEAT GENERATION PER SCHOOL DAY INCLUDES LIGHTS, STUDENTS & TEACHER		
		TYPHOON ROOM	ARKLA ROOM	HAYES ROOM		TYPHOON ROOM	ARKLA ROOM	HAYES ROOM	TYPHOON ROOM	ARKLA ROOM	HAYES ROOM	TYPHOON ROOM	ARKLA ROOM	HAYES ROOM
APRIL**	17	24.6	20.0	-	3.67	4.77	4.19	-	4.77	4.19	-	61,500	52,200	-
MAY	21	22.6	19.6	-	3.67	4.78	4.39	-	4.78	4.39	-	58,000	52,000	-
JUNE	14	26.0	23.6	-	3.67	4.66	4.42	-	4.66	4.42	-	61,400	57,400	-
JULY	NO CLASSES HELD													
AUGUST	20	24.0	29.3	0	3.42	5.00	5.00	0	3.92	3.92	0	58,300	63,700	0
SEPTEMBER	13	37.8	39.6	25.0	3.67	6.00	6.00	6.00	5.17	5.17	5.17	85,800	86,600	67,500
OCTOBER	22	31.4	32.1	26.4	3.67	6.00	6.38	6.05	8.45	5.18	5.05	77,500	78,000	69,800
NOVEMBER	18	28.4	24.9	29.1	3.67	6.33	6.50	6.00	9.17	5.50	4.98	75,900	70,700	72,900
DECEMBER	14	29.2	29.1	30.6	3.67	6.24	5.76	5.76	5.24	4.75	4.97	75,700	72,300	74,100
JANUARY	20	27.9	26.1	28.7	3.67	5.95	5.90	6.05	7.61	4.90	5.00	72,400	68,500	72,800
FEBRUARY	19	30.9	28.8	31.5	3.67	6.25	6.05	5.95	5.27	5.05	4.95	76,700	* 73,000	76,500
MARCH	23	34.1	32.6	31.6	3.67	6.21	6.74	6.17	5.22	5.75	5.17	80,700	81,500	77,200
APRIL	16	34.5	34.0	33.1	3.67									
MAY	21	36.1	36.6	35.1	3.67	6.19	6.00	5.90	5.19	5.00	4.90	83,000	80,000	83,000
JUNE (1-17)	12	34.9	36.8	33.8	3.67	6.16	6.33	6.08	5.17	5.33	4.32	81,000	85,000	79,000
YEARS AVERAGE		30.1			3.67									

* Part time teacher for to

** Data recorded from April 8-30, Extrapolated to first of month

TABLE F

PEAK COOLING LOADS
FOR DAYS DURING MONTH OF MAY 1960

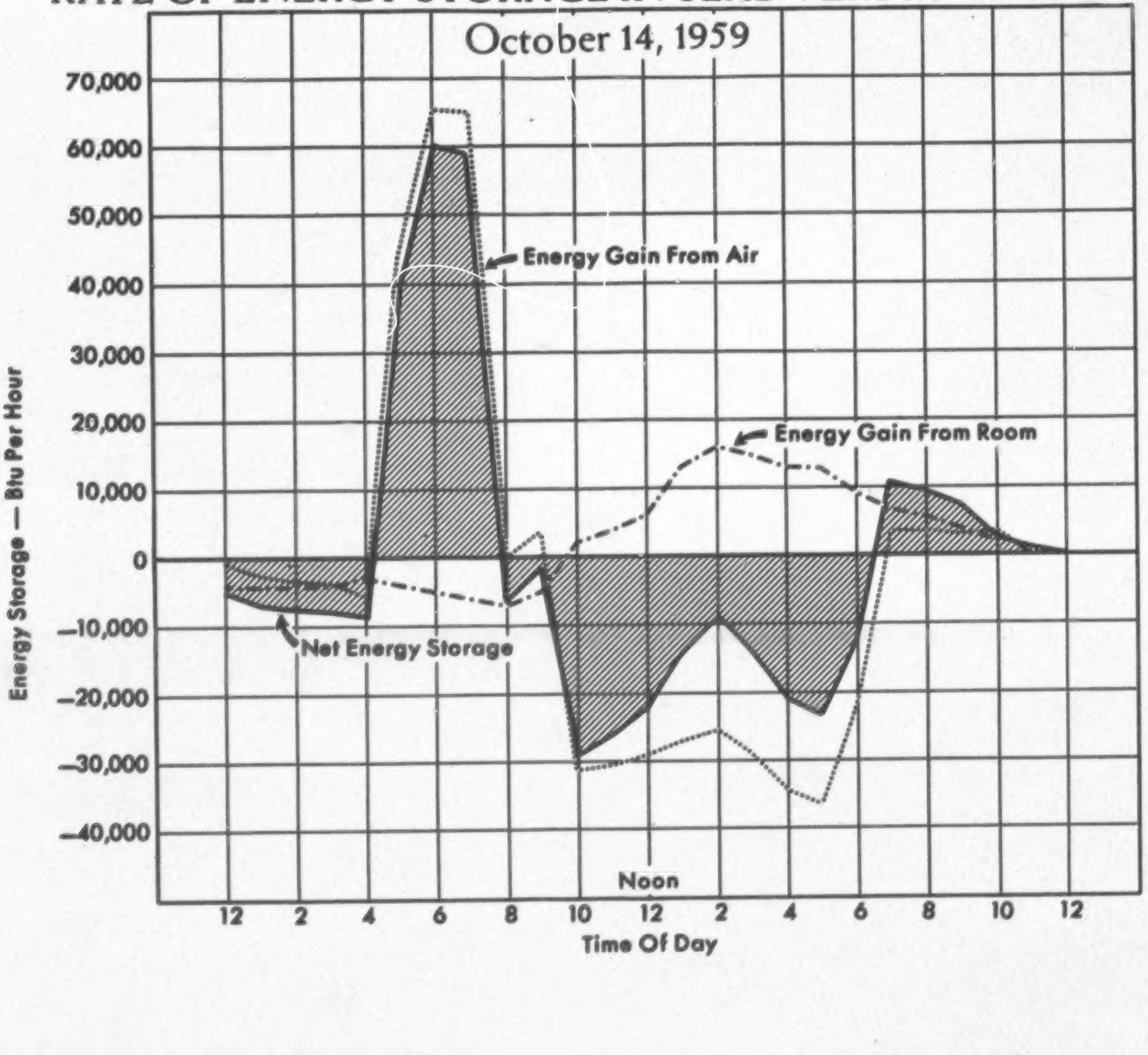
LOADS AVERAGED BETWEEN 1 PM — 3 PM

Date	Outside Temperatures			Loads (Across floor and room)		Students	
May	Ave. D.B.	Avg. W.B.	Morning Low	Absorption RM. Disch.-Return Btu/hr	Heat Pump Rm. Disch.-Return Btu/hr	Absorption Room	Heat Pump Room
16	71	57	58	40,000	44,000	38	33
5	73	59	52	46,000	48,000	34	38
17	75	58	57	41,000	42,000	38	37
25	75	59	54	43,000	42,000	38	34
13	80	62	59	39,000	40,000	36	36
26	85	62	59	36,000	40,000	38	36
12	87	64	60	38,000	38,000	35	35
10	90	64	61	40,000	42,000	35	37
11	91	64	62	42,000	42,000	35	36

Date	Loads (Across rooms only)		Loads (Across Units)	
May	Absorption Rm. Supply Reg. to Return Reg. Btu/hr	Heat Pump Rm. Supply Reg. to Return Reg. Btu/hr	Absorption Unit Btu/hr	Heat Pump Unit Btu/hr
16	13,000	12,000	36,000	38,000
5	12,000	11,000	44,000	46,000
17	13,000	13,000	40,000	39,000
25	14,000	16,000	42,000	39,000
13	15,000	14,000	40,000	41,000
26	14,000	17,000	39,000	39,000
12	16,000	16,000	40,000	40,000
10	16,000	17,000	42,000	44,000
11	18,000	18,000	44,000	35,000

RATE OF ENERGY STORAGE IN SLAB VERSUS TIME OF DAY

October 14, 1959



SUPPLEMENT TO

RESEARCH IN CLASSROOM THERMAL ENVIRONMENT

AT GARDENHILL SCHOOL
IN LA MIRADA, CALIFORNIA

Operating Costs Prepared for
Southern California Gas Company

By Clarke T. Howatt
Assistant Professor
Department of Mechanical Engineering
University of Southern California

1961

CLARKE T. HOWATT
ENGINEERING CONSULTANT
6478 NANCY STREET
LOS ANGELES 45

September 5, 1961

Southern California Gas Company
810 South Flower Street
Los Angeles, California

Dear Sirs:

Enclosed are the tables containing the monthly electricity, gas and water consumptions with the respective costs. As per your request, these costs have been obtained for a "base school", for a "base school plus twenty-three Arkla Servel Units or for twenty-three Typhoon Heat Pump units", and for a "base school with one Arkla-Servel unit or one Typhoon Heat Pump unit". These cases are described on the following pages.

The utility consumptions were obtained from the report entitled:

"Research In Classroom Thermal Environment"

Gardenhill School
La Mirada, California

Additional data was obtained from Southern California Edison Company, Southern California Gas Company, and Southwest Water Company.

The cost analysis was obtained using the following rate schedules:

Electricity:	Southern California Edison Company Schedule A-4, General Service, Demand Rate
Gas:	Southern California Gas Company Schedule G-2M
Water:	Southwest Water Company Four-Inch Meter Schedule

All of the cost figures have been rounded off to the nearest dollar.

Sincerely,

Clarke T. Howatt

Operating Cost Analysis

A part of the original agreement among the participating parties, Southern California Gas Company, Southern California Edison Company, Kistner, Wright and Wright, and Airfloor Company, was to measure energy consumptions and evaluate operating costs of the absorption and heat pump systems installed for the test class rooms at the Gardenhill School project. Individual sub-meters were installed to measure gas, electricity, and water usage by the systems. These were read and recorded at weekly intervals.

Costs are based upon energy consumptions of the test units as determined and recorded for the monthly periods indicated and upon the current utility rates applicable at Gardenhill School.

Analysis I applies to the operating costs of the actual system under test (one 3.5 ton absorption unit and one 3 ton heat pump unit). It indicates a saving of $67.00 per year or 35.6% for the absorption unit.

Analysis II indicates the costs, should the entire school be provided with either absorption or heat pump systems similar to the test installation. On this basis a possible saving of $1,621.00 or 39.0% for the absorption system is indicated.

Original equipment costs, depreciation, floor space, maintenance expense have not been included in this operating cost analysis. For the completely cooled school it was assumed that each unit installed would consume the same energy as was used by the test units. These recorded consumptions are slightly lower than the average consumptions that would actually exist, due to the fact that they were used in rooms with neither northern nor southern exposure; but were installed in rooms which had cooled rooms adjacent on either side.

In addition, the classrooms with the test units had first graders dismissed at 2:05 p.m., whereas the older children remained at school nearly an hour longer each day.

In the first analysis, a base school was determined by taking the total electricity, gas and water consumed by the entire school and subtracting the energy consumed by one Typhoon unit and one Arkla unit. A cost was computed for the energy. To this base energy was added the monthly consumptions for the Typhoon and Arkla units in separate cases and for each an energy cost determined. The base school cost subtracted from the cost, as determined individually for the test units, gave a net energy cost for the Typhoon and Arkla Units.

In the second analysis, the electricity, gas and water consumed monthly by the entire school, apart from energy used in comfort heating or cooling, was determined by subtracting from the monthly total energy consumption of the school the sum of energy consumed by two Typhoon units, two Arkla units, and nine Hayes furnaces (one furnace per two rooms). This becomes the base school consumption in the second analysis. The cost of base school electricity, gas, and water was determined by applying the following rate schedules, respectively: (a) Southern California Edison Schedule A-4 General Service, Demand Rate; (b) Southern California Gas Company Schedule G-2M; (c) Southwest Water Company Schedule Four Inch Meter. The demand to apply to the base school electrical consumption was determined by subtracting from the metered monthly demand during the test period the demand of the two Arkla units (2.8KW), the demand of the two Typhoon units (10.8KW), and the demand of the nine Hayes units (12.6KW).

It was assumed that either 23 Arkla Servel Units or 23 Typhoon Heat Pumps as used in this test would be required to provide complete cooling for the school. This was assuming four units in each of four classroom buildings, three units in a fifth classroom building and four units in the building which houses administration, multipurpose room, cafeteria, and special classrooms. The floor area of this building is approximately 10,000 square feet. For a heat pump or an absorption unit installation for the school, the base school energy was added to the corresponding energy consumed by 23 heat pumps or 23 absorption units to find the total estimated energy metered to the school. The cost of this total energy was obtained using the preceding rate schedules. The electrical demand in the two cases was obtained by taking the base school demands for each month and adding either the demands of 23 Typhoon units with an 80% diversity factor, or the demands of the Arkla Servel unit with a 90% diversity factor. The low diversity factor applied to heat pumps is due to the possibility of first stage operation of several of the units when peak demand occurred.

It is emphasized that these costs are estimated only for the Gardenhill Elementary School installation and are not necessarily applicable to other types of schools or similar schools in different areas, because of diversity and demand requirements of higher level schools.

The metered electricity, gas, and water for the test units and for the entire school, as obtained during the test period, has been interpolated where necessary in order to present the data in the following tables on a calendar month basis.

ANALYSIS I

COMPARISON OF ESTIMATED OPERATING COSTS OF AIR CONDITIONING FOR ONE ARKLA-SERVEL ABSORPTION UNIT VERSUS ONE TYPHOON HEAT PUMP UNIT

	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	TOTALS
GARDENHILL SCHOOL TOTAL CONSUMPTION														
Electricity – KWH	14,720	14,880	11,840	10,080	12,720	17,600	19,840	20,400	17,440	20,160	22,480	20,080	21,040	
Demand – KW	62.4	61.6	33.6	38.4	68.0	69.6	71.2	71.0	68.0	74.4	76.0	76.0	77.6	
Gas – cubic feet	140,000	80,000	36,000	50,000	90,000	150,000	240,000	350,000	450,000	400,000	340,000	245,000	200,000	
Water – cubic feet	85,000	110,000	122,000	140,000	95,000	68,100	44,000	38,000	8,600	4,500	28,600	68,300	77,500	
BASE SCHOOL CONSUMPTIONS – COMMON TO BOTH SYSTEMS AND COSTS ***														
Electricity – KWH	13,451	13,615	10,426	8,651	11,493	16,315	18,302	19,000	15,895	18,626	20,770	18,550	19,394	
Demand – KW	55.6	54.8	35.4*	35.4*	61.2	62.8	64.4	64.2	61.2	67.6	69.2	69.2	70.8	
Gas – cubic feet	130,100	64,000	19,700	33,400	76,100	136,500	226,100	336,800	435,300	386,000	321,700	231,500	180,700	
Water – cubic feet	84,884	109,743	121,692	139,690	94,759	67,893	43,865	37,923	8,553	4,428	28,442	68,130	77,276	
Cost of electricity	$265.00	$267.00	$205.00	$182.00	$246.00	$310.00	$338.00	$347.00	$303.00	$346.00	$375.00	$346.00	$349.00	
Cost of gas	$ 94.00	50.00	18.00	29.00	58.00	96.00	179.00	262.00	333.00	297.00	251.00	183.00	123.00	
Cost of water	$130.00	168.00	185.00	212.00	145.00	104.00	68.00	59.00	50.00**	50.00**	50.00**	105.00	118.00	
Total cost	$489.00	485.00	408.00	423.00	449.00	510.00	585.00	668.00	686.00	693.00	676.00	634.00	590.00	$7,296.00
ARKLA SYSTEM														
Added KWH of electric usage	263	353	368	374	338	318	271	229	232	238	309	299	363	
Added cubic feet of gas usage	9,900	16,000	16,300	16,600	13,900	13,500	13,900	13,200	14,700	14,000	18,300	13,500	19,300	
Added cubic feet of water usage	116	257	308	310	241	207	135	77	47	72	158	170	224	
Total KWH – electric usage	13,714	13,968	10,794	9,025	11,831	16,633	18,573	19,229	16,127	18,864	21,079	18,849	19,757	
Demand – KW	57.0	56.2	36.1*	36.1*	62.6	64.2	65.8	65.6	62.6	69.0	70.6	70.6	72.2	
Total cubic feet of gas usage	140,000	80,000	36,000	50,000	90,000	150,000	240,000	350,000	450,000	400,000	340,000	245,000	200,000	
Total cubic feet of water	85,000	110,000	122,000	140,000	95,000	68,100	44,000	38,000	8,600	4,500	28,600	68,300	77,500	
Total power cost	$270.00	$272.00	$210.00	$187.00	$252.00	$316.00	$342.00	$351.00	$307.00	$350.00	$380.00	$351.00	$355.00	
Total gas cost	$ 98.00	59.00	26.00	37.00	65.00	103.00	190.00	271.00	343.00	307.00	264.00	194.00	134.00	
Total water cost	$130.00	168.00	186.00	213.00	145.00	105.00	69.00	60.00	50.00*	50.00*	50.00*	105.00	119.00	
Total overall system cost	$498.00	499.00	422.00	437.00	462.00	524.00	601.00	682.00	700.00	707.00	694.00	650.00	608.00	$7,484.00
TYPHOON SYSTEM														
Added KWH – electric usage	1,006	912	1,046	1,055	889	967	1,267	1,171	1,313	1,296	1,401	1,231	1,283	
Total KWH – electric usage	14,457	14,527	11,472	9,706	12,382	17,282	19,569	20,171	17,208	19,922	22,171	19,781	20,677	
Demand – KW	61.0	60.2	32.2	37.0	66.6	68.2	69.8	69.6	66.6	73.0	74.6	74.6	76.2	
Total power cost	$284.00	$284.00	$220.00	$197.00	$263.00	$328.00	$360.00	$368.00	$326.00	$368.00	$398.00	$367.00	$371.00	
Total overall system cost	$508.00	502.00	423.00	438.00	466.00	528.00	607.00	689.00	709.00	715.00	699.00	655.00	612.00	$7,551.00
DIFFERENCE BETWEEN TOTAL SYSTEM COST AND BASE COST EQUALS UNIT COST														
Arkla unit cost	$ 9.00	$ 14.00	$ 14.00	$ 14.00	$ 13.00	$ 14.00	$ 16.00	$ 14.00	$ 14.00	$ 14.00	$ 18.00	$ 16.00	$ 18.00	$ 188.00
Typhoon unit cost	$ 19.00	17.00	15.00	15.00	17.00	18.00	22.00	21.00	23.00	22.00	23.00	21.00	22.00	$ 255.00
Difference	$ 10.00	3.00	1.00	1.00	4.00	4.00	6.00	7.00	9.00	8.00	5.00	5.00	4.00	$ 67.00

* 50 % of Maximum Monthly Demand for 1 Year

** Monthly Minimum Charge

*** Base School Consumption Equals Total School Consumption less 1 Arkla Servel Unit and 1 Typhoon Heat Pump Base Demand = Total Demand Less (5.4 + 1.4)

SAVINGS BY ARKLA UNIT OVER TYPHOON HEAT PUMP = $67.00

INCREASED COSTS OF OPERATION OF TYPHOON OVER ARKLA = 35.6%

Applicable Rates:

Electric	– Southern California Edison	A-4 (Demand Rate)
Gas	– Southern California Gas Company	G-2 (Costs Calculated on presently effective rates)
Water	– Southwest Water Company	4" Meter Schedule

ANALYSIS II

COMPARISON OF ESTIMATED OPERATING COSTS OF AIR CONDITIONING FOR ENTIRE SCHOOL WITH 23 ARKLA GAS AIR CONDITIONERS VERSUS 23 TYPHOON HEAT PUMPS AT GARDENHILL SCHOOL

	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	TOTALS
GARDENHILL SCHOOL														
TOTAL CONSUMPTIONS														
Electricity – KWH	14,720	14,880	11,840	10,080	12,720	17,600	19,840	20,400	17,440	20,160	22,480	20,080	21,040	
Demand – KW	62.4	61.6	33.6	36.4	68.0	69.6	71.2	71.0	68.0	74.4	76.0	76.0	77.6	
Gas – cubic feet	140,000	80,000	36,000	50,000	90,000	150,000	240,000	350,000	450,000	400,000	340,000	245,000	200,000	
Water – cubic feet	85,000	110,000	122,000	140,000	95,000	68,100	44,000	38,000	8,600	4,500	28,600	68,300	77,500	
BASE SCHOOL CONSUMPTIONS ***														
– COMMON TO BOTH														
Electricity – KWH	7,196	6,770	3,882	2,222	5,166	8,390	10,214	10,500	7,600	9,282	10,590	9,420	9,538	
Demand – KW	36.2	35.4	25.7*	25.7*	41.8	43.4	45.0	44.8	41.8	48.2	49.8	49.8	51.4	
Gas – cubic feet	24,800	12,000	3,400	12,300	31,600	36,600	33,800	19,400	35,400	30,900	33,400	38,000	30,400	
Water – cubic feet	85,000	109,000	122,000	139,000	95,000	68,000	44,000	38,000	8,500	4,400	28,000	68,000	77,000	
Cost of electricity	$164.00	$157.00	$94.00	$74.00	$135.00	$187.00	$212.00	$216.00	$175.00	$203.00	$222.00	$207.00	$210.00	
Cost of gas	$22.00	12.00	5.00	12.00	28.00	32.00	32.00	20.00	34.00	[illegible].00	32.00	36.00	27.00	
Cost of Water	$130.00	166.00	186.00	211.00	145.00	105.00	69.00	60.00	50.00**	50.00**	50.00**	105.00	118.00	
Total base cost	$316.00	335.00	285.00	297.00	308.00	324.00	313.00	296.00	259.00	283.00	304.00	348.00	355.00	$4,023.00
ARKLA - SERVEL SYSTEM														
CONSUMPTIONS – 23 ARKLA SERVEL UNITS														
Added electricity – KWH	6,050	8,120	8,460	8,600	7,770	7,320	6,230	5,270	5,340	5,480	7,100	6,880	8,350	
Added gas – cubic feet	228,000	368,000	375,000	382,000	320,000	311,000	320,000	304,000	338,000	322,000	421,000	311,000	443,000	
Added water – cubic feet	2,670	5,920	7,080	7,130	5,540	4,760	3,110	1,770	1,080	1,660	3,640	3,910	5,150	
TOTAL CONSUMPTIONS														
Total electricity – KWHR	13,246	14,894	12,342	10,822	12,936	15,710	16,444	15,770	12,940	14,762	17,690	16,300	17,888	
Demand – KW	65	64	40*	41	71	72	74	74	71	77	79	79	80	
Total gas – cubic feet	252,800	380,000	378,400	394,300	351,600	347,600	353,800	323,400	373,400	352,900	454,400	349,000	473,400	
Total water – cubic feet	87,670	114,920	129,080	146,130	100,540	72,760	47,110	39,770	9,580	6,060	31,640	71,910	82,150	
TOTAL COSTS														
Total electricity – cost	$273.00	$292.00	$236.00	$216.00	$275.00	$312.00	$324.00	$316.00	$275.00	$305.00	$345.00	$327.00	$349.00	
Total gas – cost	$117.00	162.00	161.00	168.00	150.00	149.00	274.00	260.00	288.00	274.00	346.00	271.00	225.00	
Total water –cost	$134.00	175.00	196.00	222.00	153.00	112.00	73.00	62.00	50.00**	50.00**	50.00**	109.00	126.00	
Total cost – Arkla system	$524.00	629.00	593.00	606.00	578.00	573.00	671.00	638.00	613.00	629.00	741.00	707.00	700.00	$8,202.00
TYPHOON SYSTEM														
ADDED CONSUMPTIONS														
Added electricity – KW hours	23,140	20,980	24,060	24,270	20,450	22,240	29,140	26,930	30,200	29,810	32,220	28,310	29,510	
TOTAL CONSUMPTIONS														
Electricity – KWH	30,336	27,750	27,942	26,492	25,616	30,631	39,354	37,430	37,800	39,092	42,810	37,733	39,048	
Demand – KW	136	135	107	112	141	143	144	144	141	148	149	149	151	
TOTAL COSTS														
Total electricity – cost	$570.00	$535.00	$508.00	$494.00	$513.00	$581.00	$695.00	$670.00	$672.00	$696.00	$745.00	$679.00	$698.00	
Total cost – Typhoon system	$722.00	713.00	699.00	717.00	686.00	718.00	796.00	750.00	756.00	776.00	827.00	820.00	843.00	$9,823.00
DIFFERENCE BETWEEN BASE AND TOTAL COST OF SYSTEM – COST OF AIR CONDITIONING														
Cost – Arkla power-water-gas	$208.00	$294.00	$308.00	$309.00	$270.00	$249.00	$358.00	$342.00	$354.00	$346.00	$437.00	$359.00	$345.00	$4,179.00
Cost – Typhoon power	$406.00	378.00	414.00	420.00	378.00	394.00	483.00	454.00	497.00	493.00	523.00	472.00	488.00	$5,800.00
Difference	$198.00	84.00	106.00	111.00	108.00	145.00	125.00	112.00	143.00	147.00	86.00	113.00	143.00	$1,621.00

* 50% of Maximum Monthly Demand for 1 Year

** Monthly Minimum Charge

*** Base School Equals Total Consumption Less Consumptions For 9 Hayes Units, 2 Arkla Units, 2 Typhoon Units.

SAVINGS BY ARKLA SYSTEM OVER HEAT PUMP SYSTEM = $1,621.00

INCREASED COSTS OF OPERATION OF TYPHOON OVER ARKLA = 39%

Applicable Rates:

Electric	– Southern California Edison	A-4 (Demand Rate)
Gas	– Southern California Gas Company	G-2 (Costs Calculated on presently effective rate)
Water	– Southwest Water Company	4" Meter Schedule

Note: Applied 90% Diversity